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FACTORS AFFECTING COMPOSTING OF MUNICIPAL SLUDGE IN A BIOREACTOR

by

H. A. J. Hoitink and G. A. Kuter

The Ohio State University
Ohio Agricultural Research and Development Center
Wooster, Ohio 44691

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Project Officer

Atal E. Eralp
Wastewater Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

This research was initiated to determine the feasibility of composting municipal sludge in an aerated tank bioreactor system and to develop baseline data for the rational operation and design of enclosed reactor composting systems. A variety of conditions was tested and various mixtures of recycled compost, bark, and sawdust were used as bulking agents. The mean temperature of the compost was regulated through programmed rates of airflow.

Material balances were determined from accurate measurements of the weights of solids and water in the reactor feed and reactor product. In addition, temperature, aeration and carbon dioxide evolution were monitored continuously.

Losses of water and solids experienced in this system were significantly greater than those published for the static aerated pile system. Measurements of carbon dioxide evolution appeared to accurately reflect the destruction of volatile solids and indicated that activity was at an optimum when the mean temperature of the compost was maintained at 38-55°C under high rates of aeration.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Composting is one of the alternatives available in the treatment of municipal sludges. This report details the research aimed at developing optimum operation strategies by means of temperature control.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

This research was initiated to determine the feasibility of composting municipal sludge in an aerated tank bioreactor system and to develop baseline data for the rational operation and design of enclosed reactor composting systems. A section of the reactor (24 m) was used for replicated composting trials. A variety of conditions were tested and various mixtures of recycled compost, bark and sawdust were used as bulking agents. The mean temperature of the compost was regulated through programmed rates of airflow.

Material balances were determined from accurate measurements of the weights of solids and water in the reactor feed and reactor product. In addition, temperature, aeration and carbon dioxide evolution were monitored continuously.

Losses of water and solids experienced in this system were significantly greater than those published for the static aerated pile system. Measurements of carbon dioxide evolution appeared to accurately reflect the destruction of volatile solids and indicated that activity was at an optimum when the mean temperature of the compost was maintained at 38-55 C under high rates of aeration. Experiments with a pugmill mixer indicated that thorough mixing of the reactor feed resulted in increased rates of drying and loss of solids over front-end loader mixing. Data collected on this system are in general agreement with those of others based on bench-scale reactors.

This report was submitted in fulfillment of Agreement No. CR-807791-01-0 by the Department of Plant Pathology, OARDC, OSU, Wooster, under the sponsorship of U.S. Environmental Protection Agency. This report covers the period of September 22, 1980 to July 21, 1983.

CONTENTS

Foreword iii

Abstract iv

Figures vi

Tables ix

Acknowledgment xi

Introduction 1
Description of the Reactor Vessels 5
  Data acquisition center 7
  CO_2 and O_2 measurements 9
  Data processing 10
Samping Procedures 12
  Temperature gradients in the reactor vessel 12
  Distribution of dry solids in the reactor vessel 15
  Distribution of volatile solids in the reactor 15
  Determination of free air space 25
  Chemical analyses 28
Materials Balances for Seven Composting Trials 29
  Introduction 29
  Materials balance 30
  Pugmill mixing versus FEL mixing of reactor feed 40
Specific Activity of the Compost Biota 43
Fate of Fecal Pathogens 58
Bulking Agents 72
Discussion 74
References . . . .
Appendices

  I. Calculations for the determination of airflow, mass (Kg) of dry air entering the reactor and mass (Kg) of carbon dioxide produced during each four hour interval 81

  II. Interpolation of temperature data 83

  III. Paygro system process performance summary 87

  IV. Survival of fecal pathogens I . . . .

  V. Survival of fecal pathogens II 93

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FIGURES

Number Page

1 Schematic diagram of composting facilities at Paygro Inc., 11000 Huntington Rd., South Charleston, OH 45368 4

2 Aeration equipment: 1=air intake, 2=fan and gates, 3=port where air enters plenum under the compost, 4=averaging pitot tube, 5=differential pressure transducer, 6=outside wall of building in which reactors are located, and 7=reactor vessel wall 8

3 Temperature distributions for reactor sections maintained at 65 and 42 C during preliminary summer trial 13

4 View of tank showing temperature probe positions. x indicates probe position (two in center, one each at 30 and 60 cm) from the wall in each section. Thermocouples are attached to probes in the center at depths of 15, 30, 80, 115, 135, 210, and 240 cm; near the wall thermocouples are attached at 15, 135, and 240 cm depths 14

5 Percent dry solids distribution with depth in the reactor: 2=Trial 2, distribution on March 23 after 34 days and 3=Trial 3, distribution on June 18 after 18 days in the reactor. Mean percent dry solids for reactor products of Trials 2 and 3 were 46.9 and 58.5, respectively 19

6 Temperature at various depths from surface in compost during a winter trial (2/26/81-3/3/81) with anaerobically digested sludge after the second turn: 1, 2, 3, and 4 are 7.5, 90, 150, 245 cm from the surface, respectively. 5 and 6 are daily ambient maximum and minimum temperatures, respectively 26

7 Aeration CO_2 evolution and temperature data for the "cool" (43 C) section of Trial 2. Aeration and CO_2 evolution are given for each 4 hour interval. Mean temperature and % of Reactor Volume $>$ 55 C are based on readings from 20 thermocouples. The compost was turned once after 9 days and removed from the reactor 6 days later 44

8 Aeration, CO_2 evolution and temperature data for the "hot" (65 C) section of Trial 2. Aeration and CO_2 evolution are

(continued)

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FIGURES (continued)

Number Page

given for each 4 hour interval. Mean temperature and % of Reactor Volume > 55 C are based on readings from 20 thermocouples. The compost was turned once after 9 days and removed from the reactor 6 days later 45

9 Relationship between CO_2 evolution and mean compost temperature in Trial II. ="cool" section before turn, O="cool" section after turn, ="hot" section before turn, ="hot" section after turn 47

10 Aeration, CO_2 evolution, and temperature data for "cool" section of reactor before first turn in Trial VII 49

11 Aeration, CO_2 evoluiton, and temperature data for "cool" section of reactor after turn in Trial VII 50

12 Aeration, CO_2 evolution, and temperature data for "hot" section of reactor before turn in Trial VII 51

13 Aeration, CO_2 evolution, and temperature data for "hot" section of reactor after turn in Trial VII 52

14 From page 316 in Haug, R. T., 1980, Compost Engineering. Principles and Practice. Ann Arbor Science. Publishers, Inc., The Butterworth Group, P. O. Box 1425, Ann Arbor, MI 48160 . . . 57

15 Mean temperature (C) and percent of compost above 55 C during Trial VII. Circled numbers indicate times for which temperature distributions were plotted (Figs. 16-22) 60

16 Temperature distribution at hour 8. Mean temperature=26.3 C. Percent of compost above 55 C=0.0% 61

17 Temperature distribution at hour 24. Mean temperature=33.9 C. Percent of compost above 55 C=0.0% 62

18 Temperature distribution at hour 52. Mean temperature=65.9 C. Percent of compost above 55 C=69.8% 63

19 Temperature distribution at hour 136. Mean temperature=65 C. Percent of compost above 55 C=69.8% 64

20 Temperature distribution at hour 148. Mean temperature=76.5 C. Percent of compost above 55 C=100% 66

(continued)

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FIGURES (continued)

Number Page

21 Temperature distribution at hour 176. Mean temperature=64.9 C. Percent of compost above 55 C=80.3% 67

22 Temperature distribution at hour 212. Mean temperature=54.0 C. Percent volume above 55 C=53.7 68

23 Mean temperture and percent of compost. 55 C for two sections (2, 3) of reactor vessel during Trial III 70

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TYPING GUIDE SHEET

TABLES

Number Page

1 Arrangement of data contained in working files. Missing data are indicated by -0000. 0 11

2 Mean percent solids distribution in the reactor after 34 days of composting for a winter trial 16

3 Mean percent solids distribution in the reactor at time of second turn (day 11) for a summer trial 17

4 Mean percent solids distribution in the reactor at time of removal (day 18) for a summer trial 18

5 Description of components and reactor feed mixture for a preliminary summer trial 20

6 Materials balance for a preoliminary summer composting trial . 21

7 Mean percent volatile solids distribution in the reactor at time of second turn (day 11) for a summer trial 22

8 Mean percent volatile solids distribution in the reactor at time of compost removal (day 18) for a summer trial 23

9 Mean tempertures of compost in various thermocouple positions for selected time periods for a summer trial 24

10 Mean percent volatile solids distribution in the reactor after 34 days of composting for a winter trial 27

11 Materials balance for Trial I. Compost retention time=12.6 days. Volume of reactor feed=473 cubic yards 31

12 Materials balance for Trial II. Compost retention time=14.75 days. Volume of reactor feed=473 cubic yards 32

13 Materials balance for Trial III. Compost retention time=15 days. Volume of reactor feed=673 cubic yards 33

14 Materials balance for Trial IV. Compost retention time=20.25 days. Volume of reactor feed=663 cubic yards 34

(continued)

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TABLES (continued)

Number		Page
15	Materials balance for Trial V. Compost retention time=21.7 days. Volume of reactor feed=581 cubic yards	35
16	Materials balance for Trial VI. Compost retention time=15.3 days. Volume of reactor feed=473 cubic yards	36
17	Materials balance for Trial VII. Compost retention time=12.6 days. Volume of reactor feed=473 cubic yards	37
18	Mean dry solids (% DS) and volatile solids (% VS) of components, reactor feed and reactor product for seven composting trials. Mean compost retention time=16.0 days . .	38
19	Percentage loss of wet weight, weight dry solids and weight water. Number of days retention and mean high and low ambient air tempertures for compost Trials I-VII	39
20	Dry solids (%) obtained in Trial V using front end loader (FEL) and pugmill mixed (speed flow)	42
21	Percent dry solids (% DS), percent volatile solids (% VS) and percent loss of initial weight of dry solids for "cool" and "hot" sections of Trial VII	48
22	Comparison between carbon dioxide evolution values and calculated values based on stiochiometric formulae for Trial VII	55
23	Carbon dioxide production and oxygen uptake determinations for "cool" and "hot" sections of Trial VII	56

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INTRODUCTION

During the past decade composting has become of increasing importance for the ultimate treatment of municipal sludges in the United States. Windrow composting is used successfully in the arid parts of the Southwest and the aerated static pile has been adopted widely in the Northeast (1, 4, 12, 16). In both systems, during wet weather, there are significant levels of anaerobic and microaerophilic metabolism which may result in serious odor problems.

Present trends in the U.S. are to install enclosed systems to avoid nuisances associated with exposed systems and reduce labor and operating costs through mechanized materials handling. In Europe a variety of enclosed composting systems have been in use for several years. Although several types of silo systems predominate in Europe, none are in operation in the U.S. However several of these systems are in the planning stage at this time.

At the present time, research on various composting systems is based on a small number of studies using laboratory or bench-scale composters (2, 3, 5, 8, 9, 10, 14, 15). Engineering principles have been developed from such data (6) however there have been few studies on large scale or pilot scale composting. Furthermore, there are no published studies which have examined composting in a full scale enclosed reactor. Thus rational guidelines for the operation and engineering of these systems must be derived from studies of other systems.

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Recently valuable information has been published from Rutgers University on parameters affecting the performance of the aerated static pile. For example, rates of drying and apparently decomposition were highest when temperatures within the compost were maintained at between 35-55 C (11). These results, obtained in a pilot scale study, have important implications for all composting systems.

It is the purpose of this study to present quantitative data on composting of municipal sludge in a full scale reactor vessel. Four sections of an existing tank system used to compost cow manure were modified for experimentation. Quantitative data are presented on drying, loss of dry and volatile solids, and rates of aeration and carbon dioxide evolution. The performance of the system is evaluated by measuring the rates of carbon dioxide evolution in the reactor and by examining the effects of various temperature conditions on these rates.

The report also presents detailed analyses of the temperature gradients within the reactor. The significance of the temperature distribution in terms of pathogen reduction is discussed. In addition, the effects of using various bulking agents, the continued use of recycled compost as bulking agent and the impact of different compost mixing procedures are discussed. The information presented in this report serves as a sound quantitative basis for the rational design and operation of enclosed reactor systems.

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DESCRIPTION OF THE REACTOR VESSELS

A schematic drawing of the Paygro system located at Paygro, Inc., 11000 Huntington Rd., South Charleston, OH 45368, is presented in Fig. 1. It consists of two reactors each 121.9 x 6.1 m (400 x 20 ft). The reactors are 3 m (10 ft) deep. The base consists of a perforated metal floor below which is an air space. Air is forced by fans through an opening in one wall into the airspace and up through the perforated floor into the reactor. Centaxial tubular centrifugal fans (7 1/2 HP motors) made by Aerovent Inc., Piqua, OH, are located at 12.1 m (40 ft) distances along the base of each reactor. A layer of pea gravel is positioned permanently on top of the perforated floor. A layer of compost remains in the reactor each time that it is emptied by the extractoveyor (see Fig. 1).

Sludge and bulking agent were mixed on an outdoor concrete pad with front end loaders (FEL). In one trial a pugmill mixer was used for further blending. The reactor feed was loaded by FEL into a live-bottom feed hopper and moved into the reactors via a continuous belt, tripper car and indexing conveyor. The compost was turned or removed by the extractoveyor, loaded into trucks, weighed and stored in curing piles or mixed into the reactor feed of the following trial as recycled compost (Fig. 1).

In preliminary experiments it was observed that air moved between sections of the reactor aerated by adjacent fans. In the 24 M (80 ft) experimental section of the reactor therefore, modifications were made which significantly reduced air leakage from the one vessel to the next. It was

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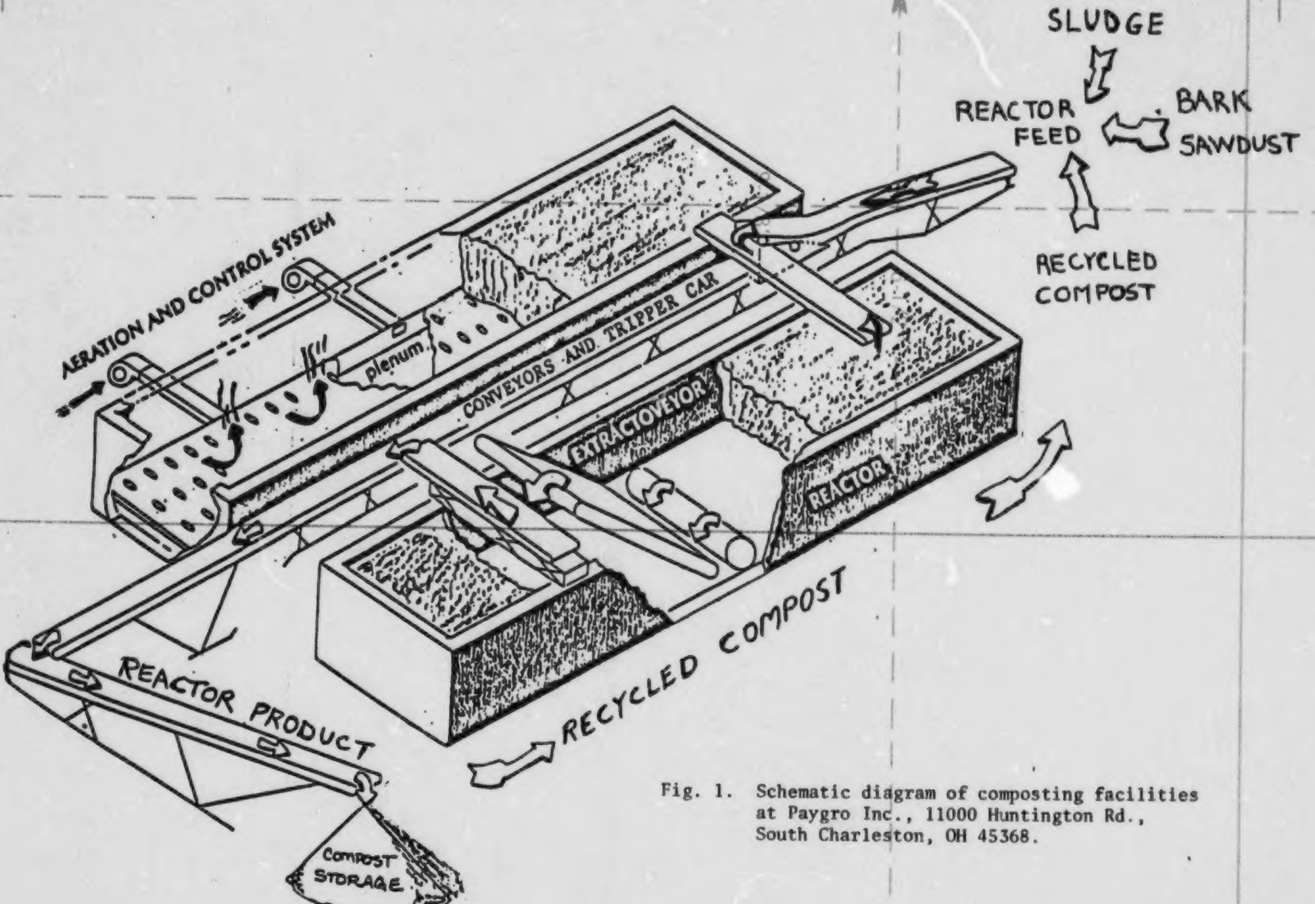
SLUDGE
REACTOR FEED
BARK
SAWDUST
RECYCLED COMPOST
AERATION AND CONTROL SYSTEM
plenum
CONVEYORS AND TRIPPER CAR
EXTRACTOVEYOR
REACTOR
RECYCLED COMPOST
REACTOR PRODUCT
COMPOST STORAGE

Fig. 1. Schematic diagram of composting facilities at Paygro Inc., 11000 Huntington Rd., South Charleston, OH 45368.

also discovered that fans did not supply enough air to maintain low temperatures in the compost in each 12 M section during summer trials. This problem only occurred during the first two days after compost was loaded into the reactor. Two additional fans, therefore, were installed so that four vessels were available, each 6 m long, 6 m wide and 3 m deep (108 m^3/vessel). The total depth of compost that could be loaded into the reactor was 290 cm.

A plank was positioned on top of each buffer zone in the base of the reactor between each vessel section. During loading, sheets of polyethylene were attached to the plank, so that sections were separated from each other to the top of the reactor by "polyethylene walls" buried in the compost. The extractoveyor cut vertically through the compost up to the "wall" so that all compost placed into each section could be recovered with a minimum of contamination from the adjacent vessel.

The two vessels in the middle of the experimental section functioned independently from each other. However air leaks still existed in the outer vessels. All experiments therefore, were performed in the center vessels. The outer vessels served as buffers with treatments as similar to the center vessels as possible.

Two systems for regulation of airflow were tested in preliminary trials. In one system thermocouples activated fans via a controller to supply air. Gates on the air intake end could be closed manually to decrease airflow. In the other system the controller regulated a gate so that airflow was reduced rather than stopped entirely, until temperatures rose over a set point and the gate was opened automatically to increase airflow and therefore cool the compost. Significant problems occurred with

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the automatic system because small gate openings interfered with pitot tube readings. Furthermore constant low rates of airflow caused freezing in the base of the reactor during cold weather, whereas sudden bursts of airflow did not. It was decided to regulate airflow by an all or no-air system in which fans were turned on automatically once temperatures exceeded the programmed temperature.

Airflow sensing equipment was calibrated by R. D. Fox, Professor, Department of Agricultural Engineering, USDA, OSU, Wooster, OH 44691. Averaging pitot tubes (PSE, Inc., 41227-I94X-Way Service Dr., VanBuren Township, Belleville, MI 48111; Series 100 PAR70, standard flow sensor) were installed in 40.6 cm (16 inch) diameter 7.3 m long (24 ft) ducts ahead of the intake end of each fan (Fig. 2). Magnehelic differential pressure transducers calibrated with an inclined manometer provided a signal output which was interfaced with a data acquisition center. The magnehelic pressure transducers were mounted in heated chambers to avoid interference caused by low ambient temperatures in the winter. Pitot tubes were calibrated by comparing readings with those of a heated thermocouple anemometer (Hastings model). Airflow in the duct could be estimated by Vave=0.9 x velocity at the center of the tube. The velocity profile across the duct was nearly uniform. Gate position (just ahead of the fan) had a slight effect on air velocity measurement. At the 1/4 flow postion, the pitot tube air velocity measurements were somewhat greater than heated thermocouple values. This probably was due to disturbance in airflow at the pitot tube in the duct which changed air velocity profiles across the duct. Gates, therefore, were not closed to less than the 1/3 flow position in experiments. It was concluded that a constant factor could be used to

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correct pitot tube readings to yield accurate measurements on the quantity of air entering the reactor.

Relative humidity of air entering the reactor was measured twice daily with a sling psychrometer (dry-wet bulb type) so that the amount of dry air entering the reactor could be calculated.

Fans generally were controlled through feed back from thermocouples by a Kaye Instruments data logger/controller (Kaye Instruments, 15 DeAngelo Drive, Bedford, MA 01730). This system equipped with a RAMP processor could be programmed to activate fans separately and maintain preset temperatures in each of the four vessels. During start up of a given test fans were operated by 10 min or 30 min timers which could be set to provide 1 min increments of aeration. Once a mean preset temperature point was reached, the data logger/controller took over automatically and controlled the fans.

Data acquisition center. An automated system for monitoring process temperature, airflow and CO_2 production in each of four vessels was designed and installed by Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201. The entire system was installed in a mobile laboratory (trailer) directly adjacent to the experimental vessel section. Temperature in the trailer was maintained at 18-20 C. The Kaye RAMP/processor, a Beckman CO_2 analyzer, a pump, solenoid valves, timers, a balance and a forced air oven were located in the trailer. The RAMP/processor was programmed at the beginning of each trial to record temperature measurements from 80 locations in the vessels, the ambient temperature and the temperature of the air entering the fans. In some experiments additional temperature mesurements were made at various locations in the exhaust air above the compost. Readings were recorded hourly by a paper printer and every 4 hr on magnetic

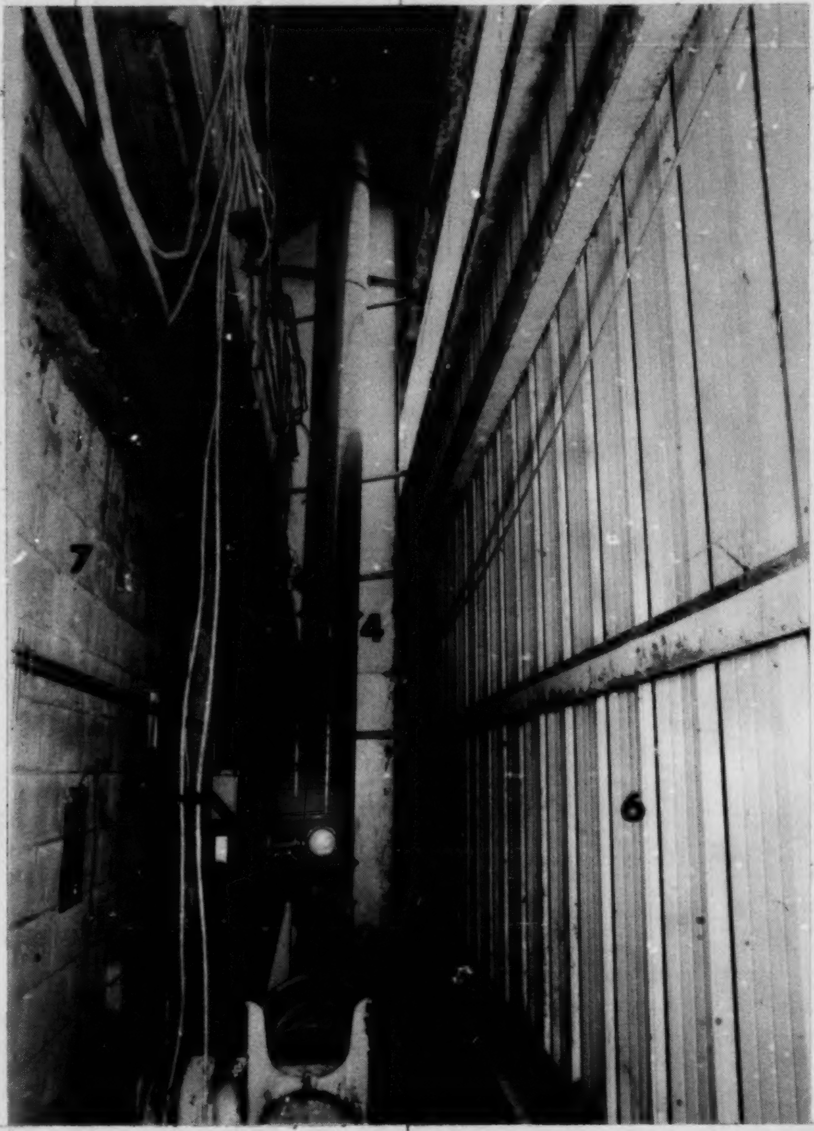

Fig. 2. Aeration equipment: 1=air intake, 2=fan and gates, 3=port where air enters plenum under the compost, 4=averaging pitot tube, 5=differential pressure transducer, 6=outside wall of building in which reactors are located, and 7=reactor vessel wall.

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tape with an MFE model 2500 tape deck (MFE Corp., Keewaydin Dr., Salem, NH 03079) that was interfaced with the RAMP/processor. The mean temperature of 20 thermocouples in each section was monitored continuously and used to regulate aeration. Temperature set points were programmed for each section and alarm relays were used to turn fans on and off. Each time the fans were activated the event was recorded in Julian date and time of day. From this data the number of minutes that fans were supplying air to the compost could be determined accurately. Readings from the pressure transducers were recorded hourly on paper tape and every 4 hr on magnetic tape. In addition manual readings were taken twice daily to check the values.

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Facilities in the trailer were used to determine percent dry solids by oven drying of pre-weighed samples. Other analyses were performed at OSU, OARDC in Wooster.

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CO_2 and O_2 measurement. Five two-liter beakers were buried upside down 45 cm deep inside each vessel and connected via a manifold, condensate flask and dryer (Dryrite) to a Beckman infrared CO_2 analyzer. Air was pulled under vacuum out of each vessel, dried and analyzed for CO_2 concentration after a constant CO_2 value was reached in the dry air moving through the analyzer. Readings for each vessel were taken automatically every 4 hours and printed on paper tape. The CO_2 system was calibrated routinely by introducing 10% CO_2 from a standard pressurized cylinder into the manifold on the compost pile. The oxygen concentration in exhaust air was measured manually with a Teledyne O_2 electrode. Periodically manual O_2 and CO_2 readings were made with a Fyrite gas analyzer. The sum of O_2 and CO_2 values varied from 18 to 21%.

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Data processing. The data recorded on magnetic tapes was processed with a Hewlett-Packard 87 computer and programs written by Dr. L. Rossman, Wastewater Research Division, MERL, US-EPA, Cincinnati, OH 45268. The data were first transferred from the tapes to raw data files on computer discs. From the raw data files the data were transformed into working files. In these working files the data were tabulated for each of the four reactor sections (I-IV) for 4 hr time intervals. The data in the working files (Table 1) included the following: the temperature of the air entering the fans (AMB TEMP), the relative humidity (REL HUMID), temperature at 13 locations within each section [T(-1)-T(-13)], the mean of 20 thermocouples in each section used to regulate fans (AVG TEMP), the differential pressure measured in the fan duct (FAN PRESS), the amount of time that the fans were running during the 4 hr period (FAN ON HRS), and the percent carbon dioxide in the air moving out of the compost (CO_2). These data were then checked against the paper printouts and manual records and all necessary corrections were made. Data in the working files were then used to determine the air flow (CFM and kg dry air) and the CO_2 produced (kg CO_2) for each section during each four hour interval. The formulae used to calculate these values are given in Appendix I. In addition, the temperature distribution data were used to calculate a weighted mean temperature which more accurately reflected the temperature in the compost and the percentage of the compost that was between selected temperature intervals. The formulae used in these determinations are included in Appendix II.

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Table 1 . Arrangement of data contained in working files. Missing data are indicated by -9999. 0.

```
----------------------------------------------------------------------
RECORD #   4 ###### HOUR   8 ###### AMB TEMP   7.9 ###### REL HUMID   88.00
Section                I              II             III             IV
                 ------------------------------------------------------
T( 1)               50.9            46.4            49.9            36.8
T( 2)               37.8            43.9            46.6            36.9
T( 3)            -9999.0            31.0            31.0            17.2
T( 4)               58.7            46.1            50.1            37.2
T( 5)               58.3            60.9            62.3            30.3
T( 6)               38.6            40.3            56.7            54.6
T( 7)               34.2            30.5            30.1            26.9
T( 8)               37.0            40.0            40.1            26.2
T( 9)               48.5            43.9            55.3            57.5
T(10)               30.6            27.7            27.4            27.8
T(11)               31.3            29.0            25.1            25.2
T(12)               36.6            32.0            28.2            24.5
T(13)               56.7            50.7            66.3            64.6
AVG TEMP            41.8            38.8            40.8            35.3
FAN PRESS           .489            .095            .082            .464
FAN ON HRS         4.000            .800            .800            .800
CO2                9.450          14.220          14.600          13.280
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SAMPLING PROCEDURES

Six preliminary trials were performed in the winter and summer of 1981. The objectives of these trials were to determine 1) whether municipal sludge could be composted effectively in the Paygro system, 2) procedures for sampling of the compost in the reactor and 3) procedures for monitoring the rate of composting. It was observed early that significant vertical gradients existed in the reactor which complicated sampling procedures. Each is discussed separately.

Temperature gradients in the reactor vessel. Preliminary mid-winter and summer trials (1981) showed that temperature readings at a depth of 50 cm were uniform across the entire reactor up to a 50 cm distance from either side wall. However, temperatures varied greatly with depth and particularly in the center of the reactor. Since temperature variation was symmetric, all probes were positioned in one half of the reactor. Examples of temperature gradients are presented in Fig. 3. Isotemps are based on means of all readings throughout a 14 day trial (Sept., 1981) for 40 thermocouple positions in each vessel. Based on this temperature distribution data it was decided to place two probes with seven thermocouples each in the center of the reactor (thermocouple depths of 15, 30, 80, 115, 135, 210 and 240 cm) and one probe with three thermocouples (depths of 15, 135, and 240 cm) at 30 cm from the wall and another with three at a 60 cm distance from the wall. A total of 20 thermocouples therefore were placed in each of four reactor vessels as illustrated in Fig. 4.

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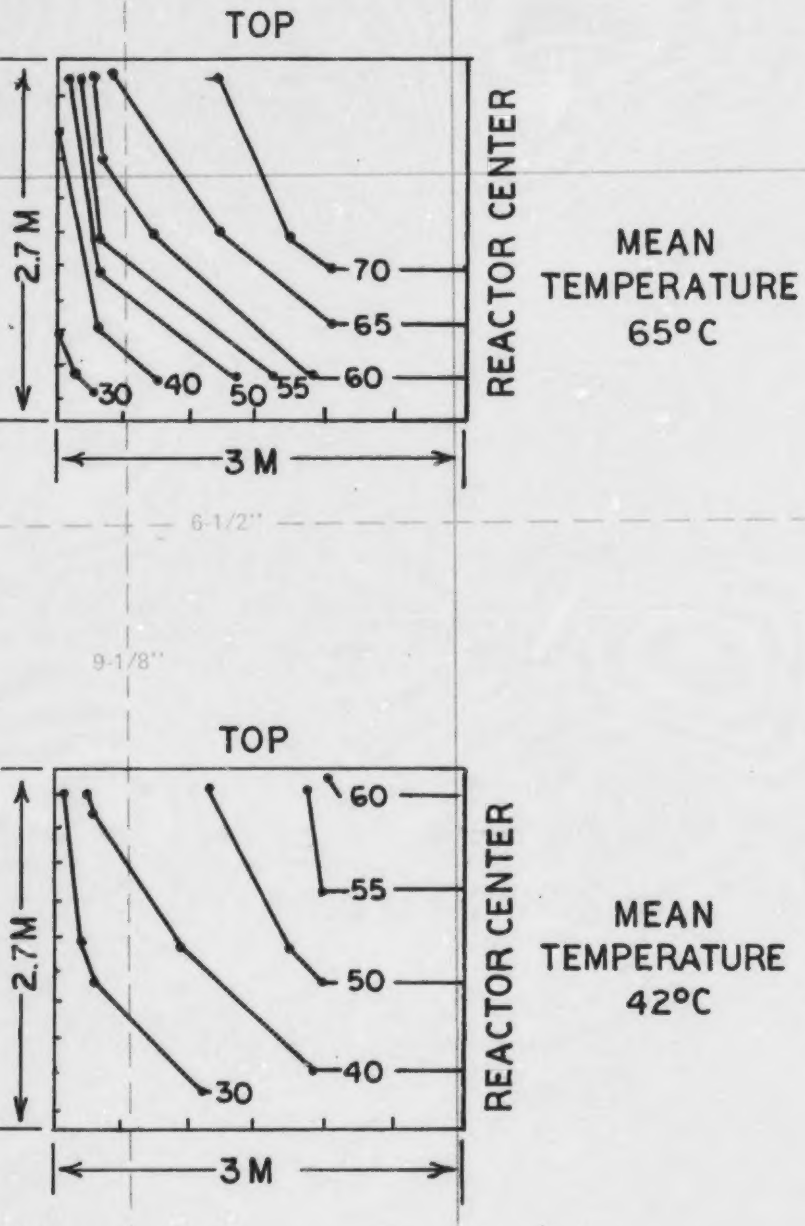

Fig. 3 . Temperature distributions for reactor sections maintained at 65 and 42C during preliminary summer trial.

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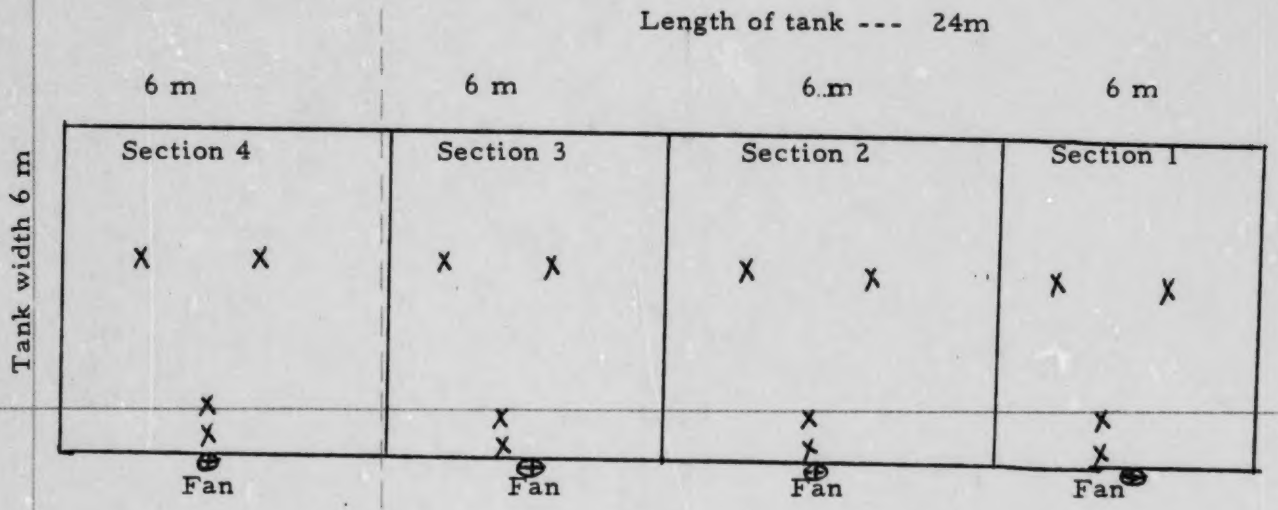
Length of tank --- 24m
6 m
6 m
6 m
6 m
Section 4
Section 3
Section 2
Section 1
Tank width 6 m
X
Fan
Fan
Fan
Fan

Fig. 4. View of tank showing temperature probe positions. x indicates probe position (two in center, one each at 30 and 60 cm) from the wall in each section. Thermocouples are attached to probes in the center at depths of 15, 30, 80, 115, 135, 210, and 240 cm; near the wall thermocouples are attached at 15, 135, and 240 cm depths.

Distribution of dry solids in the reactor vessel. Distribution of dry solids was examined in both winter and summer trials. This was accomplished by removing samples from a vertical cut made by the extractoveyer through the compost. Horizontal dry solids gradients were not detected at any depth in either winter or summer trials (Table 2, 3 and 4) which supports symmetry found for horizontal temperature readings. However samples removed from various depths in the reactor vessels differed significantly (P=0.05). During winter trials the top 50 cm layer in the reactor had the lowest dry solids level. During summer trials this top wet layer usually was 15 cm deep or less. A comparison of dry solids gradients for a summer and winter trial are presented in Fig. 5. A description of the reactor feed and a materials balance for this summer trial are presented in Tables 5 and 6.

Distribution of volatile solids in the reactor. Samples removed from the face of vertical cuts in the ractor vessels for determination of dry solids were also analyzed for volatile solids. After drying, samples were ground to a fine powder in a Wiley mill. Percent volatile solids was then determined by ashing 1 g oven dry subsamples (minimum of 1 hr at 550 C). In a summer trial samples were removed at day 11 (Table 7) and at day 18 (Table 8). A slight vertical gradient in volatile solids levels was detected in the summer test (Table 8) after 18 days of composting. No evidence of horizontal volatile solids gradients was detected at either time. Temperature distribution data within the compost are presented in Table 9 for this 18 day summer trial.

In a preliminary winter trial compost was left without turning in the reactor for 34 days to examine long range effects. Highly significant differences in levels of volatile solids were found among samples from

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TABLE 2. Mean percent solids distribution in the reactor after 34 days of composting for a winter trial.

Depth (cm from surface)	Distance from wall (cm)							Means for depth[1]
	15	150	230	300	380	460	580	
7.5	36.9[2]	38.0	36.1	37.8	35.3	35.6	35.3	36.4
15	49.4	39.7	40.8	38.9	37.1	37.8	42.6	40.9
60	45.1	46.6	47.5	46.2	51.3	46.1	48.1	47.2
120	48.9	50.2	49.9	49.8	50.0	50.2	48.3	49.6
150	47.3	53.8	49.7	49.8	49.4	49.9	46.8	49.5
210	57.0	52.8	55.8	57.2	55.3	54.3	48.2	54.3
245	53.3	52.1	53.7	52.5	50.2	50.4	48.6	51.5
Mean for distance from wall[3]	48.3	47.6	47.6	47.5	46.9	46.3	45.4	

---

[1] Mean (of 14 samples) joined by a common line are not significantly different according to Duncan's new multiple range test. $LSD_{.05}=2.6$.

[2] Mean of two samples.

[3] Means of 14 samples. No significant differences (P=.05).

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TABLE 3. Mean percent solids distribution in the reactor at time of second turn (day 11) for a summer trial.

Depth (cm from surface)	Distance from wall (cm) 15	60	200	275	340	500	Means for depth[1]
5	38.0[2]	39.3	36.9	40.5	40.4	37.6	38.8
7.5	50.9	53.1	47.4	47.0	46.4	45.3	48.3
80	52.4	52.9	50.6	51.7	50.0	49.6	51.2
130	51.9	50.0	51.1	51.7	52.2	51.4	51.4
185	49.9	49.7	52.1	54.6	52.3	51.8	51.6
240	50.3	54.0	53.0	52.2	52.0	55.0	52.7
Means for distance from wall[3]	48.8	49.8	48.5	49.6	48.9	48.5	

[1] Means (of 24 samples each) joined by a common line are not significantly different according to Duncan's new multiple range test LSD$_{.05}$=1.5.

[2] Means of four values.

[3] No significant difference among means (P=0.05).

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TABLE 4. Mean percent solids distribution in the reactor at time of removal (day 18) for a summer trial.

Depth (cm from surface)	Distance from wall (cm) 15	60	200	275	340	500	Means for depth[1]
5	41.2[2]	40.8	41.9	41.3	41.0	40.6	41.1
7.5	59.6	54.3	50.6	50.0	54.9	54.6	54.0
80	60.5	58.1	56.7	56.0	56.6	57.5	57.6
130	62.7	60.2	57.6	56.3	57.6	55.9	58.4
185	58.6	60.1	60.1	57.7	56.7	58.3	58.6
240	57.2	55.1	60.0	62.6	61.2	60.3	59.4
Mean for distance from wall[3]	56.6	54.8	54.6	54.0	54.7	54.6	

[1] Means (of 24 samples each) joined by a common line are not significantly different according to Duncan's new multiple range test $LSD_{.05}=1.6$.

[2] Mean of four values.

[3] Means (of 24 samples) joined by a common line are not significantly different according to Duncan's new multiple range test. $LSD_{.05}=1.6$.

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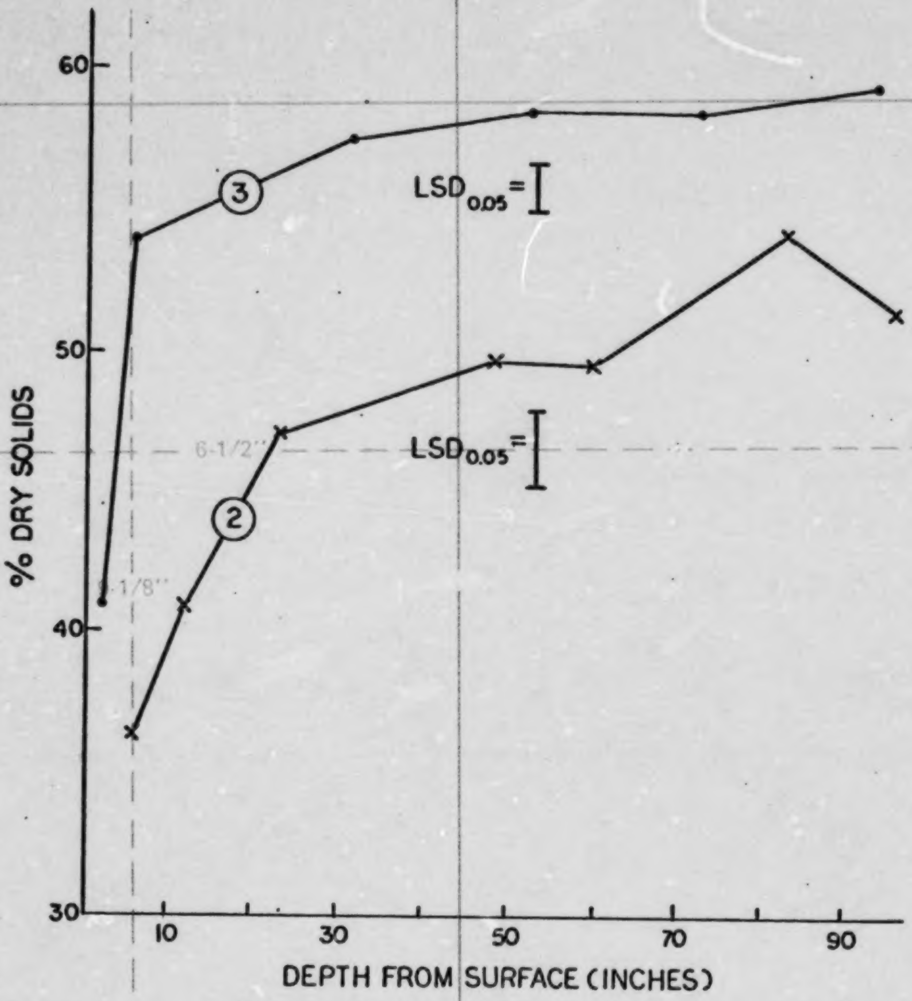

Figure 5. Percent dry solids distribution with depth in the reactor: 2=Trial 2, distribution on March 23 after 34 days and 3=Trial 3, distribution on June 18 after 18 days in the reactor. Mean percent dry solids for reactor products of Trials 2 and 3 were 46.9 and 58.5, respectively.

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Table 5. Description of components and reactor feed mixture for a preliminary summer trial.

Component	Mixing ratio (volumes)	Bulk density kg/m^3 [1]	Mean % solids	Mean % volatile solids[2]
Raw sludge[3]	1	1063	14.5	72.7
Recycled compost	2.8	605	51.8	65.3
Bark	1.6	414	57.2	84.5
Reactor feed[4]	-	679	40.8	72.9

[1] Determined by compacting (0.7 kg/cm^2, 10 lbs/sq in) samples into a 28.3 liter (1 cu ft) square box.

[2] Mean of 10 or more samples of approximately 100 gm wet weight each.

[3] Raw municipal sludge (98.4 M tons net weight) was obtained (5/26/81) from the Southerly Treatment Plant, Columbus, OH.

[4] Total volume-439 m^3 (error $<$ 4%).

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TABLE 6. Materials balance for a preliminary summer composting trial.

	Volume[1] (m^3)	Bulk[2] density (kg/m^3)	Wet[3] weight (M tons)	% Dry[4] solids	% Volatile[4] solids	Weight dry[5] solids (M tons)	Weight[5] water (M tons)	Weight[5] volatile solids (M tons)
Reactor feed	439.4	678.5	298.2	40.8	72.9	121.7	176.5	88.7
Reactor product	341.0	517.7	176.5	58.5	67.8	103.3	73.2	70.0
Loss during composting[6]	98.4		121.7			18.4	103.3	18.7
% loss	22.4		40.8			15.1	58.5	21.1

[1] Measurements were made in the reactor (error 4%).

[2] See Table 1 for explanation.

[3] Calculated from bulk density and volume.

[4] Means of a minimum of 10 samples of approximately 100g wet weight each.

[5] Calculated from we weight and percent solids or volatile solids.

[6] After 18 days in the reactor.

TABLE 7. Mean percent volatile solids distribution in the reactor at time of second turn (day 11) for a summer trial.

Depth (cm from surface)	Distance from wall (cm) 15	60	200	275	340	500	Means for depth[1]
5	69.7[2]	70.1	69.9	69.8	69.8	67.9	69.2
7.5	69.6	69.5	67.6	68.7	70.1	70.6	69.3
80	72.9	71.5	67.1	71.9	67.7	71.6	70.5
130	67.9	72.1	70.6	69.8	70.2	72.3	70.5
185	70.4	70.1	70.5	67.6	69.9	72.8	70.2
240	75.1	69.6	68.3	67.4	69.6	68.7	69.8
Mean for distance from wall[3]	70.9	70.6	68.5	69.2	69.6	70.7	

[1] Means (of 24 samples each) joined by a common line are not significantly different according to Duncan's new multiple range test (P=0.05).

[2] Mean of four values.

[3] $LSD_{0.05}$=1.80.

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TABLE 8. Mean percent volatile solids distribution in the reactor at time of compost removal (day 18) for a summer trial.

Depth (cm from surface)	Distance from wall (cm) 15	60	200	275	340	500	Means for depth[1]
5	62.9[2]	66.9	65.0	68.3	66.2	66.0	65.9
7.5	74.6	65.2	63.6	63.4	63.7	62.4	64.4
80	64.1	61.8	62.6	64.0	61.8	64.3	64.4
130	65.3	65.3	65.3	65.2	63.8	63.7	63.9
185	63.7	65.0	65.2	63.1	63.7	62.5	63.9
240	64.6	63.1	66.8	63.7	63.1	64.9	63.1
Mean for distance from wall[3]	63.8	64.5	64.7	64.6	63.7	64.0	

[1] Means joined by a common line are not significantly different according to Duncan's new multiple range test $LSD_{0.05}=1.4$.

[2] Mean of four values.

[3] No significant difference among means (P=0.05).

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TABLE 9. Mean temperatures of compost in various thermocouple positions for selected time periods of a summer trial.

Total hours elapsed	Depth (cm)	Distance from wall (cm)[1]				
		Wall	15	30	60	200
88	7.5	-[2]	-	-	-	-
	80	-	-	-	-	73.1
	130	31.4	33.5	41.7	44.0	71.4
	240	20.3	22.2	24.6	35.2	59.3
First Turn						
184	7.5	34.3	47.8	49.9	51.1	58.9
	80	-	-	-	-	59.0
	130	32.9	36.0	34.7	49.4	54.5
	240	22.4	18.4	24.6	30.9	34.9
Second Turn						
160	7.5	45.7	53.0	53.6	54.6	59.2
	80	-	-	-	-	59.5
	130	39.4	41.5	41.8	40.3	56.5
	240	25.3	26.4	24.0	29.3	37.0
Removal						
432 (total)	7.5	39.1	49.7	51.2	52.4	59.0
	80	-	-	-	-	62.5
	130	34.4	36.9	38.3	45.7	59.0
	240	22.7	21.5	25.7	31.5	41.3

[1] Means of readings taken every 4 hr in four locations for the wall, 15, 30 and 60 cm positions. Means of eight locations for the 200 cm position.

[2] Missing data.

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various depths but not among samples removed from the same depth (Table 10). The lowest levels were in the bottom of the reactor (Table 6) suggesting that more decomposition had occurred in this lower temperature location of the reactor (Fig. 6). However because dry solids and other factors also varied significantly along this vertical gradient, no causal relationship between temperature and volatile solids destruction could be determined from this data. The distribution of volatile solids data however further support horizontal symmetry in the reactor.

To reduce sampling error caused by the vertical gradients for the determination of dry and volatile solids levels of the compost for each vessel section, samples were taken after compost was removed and had been mixed thoroughly with the extractoveyor. A total of eight 125-150 g (wet wt.) samples were taken at constant intervals per vessel. Compost from each section was loaded onto eight trucks, weighed and sampled before it was returned to the reactor during turning. One sample was taken per truck load. Samples were dried in a 104 C forced air oven to constant weight to determine percent dry solids.

Determination of free air space. In preliminary trials several procedures were tested, including core samples typically used for the Leamer and Shaw desorption apparatus and an air pycnometer. Neither system provided reproducible data probably because the reactor feed was plastic whereas the product was solid. The reactor feed compacted ahead of the core sampler as it was forced into the compost, thus reducing air-filled pore space. The procedure which did produce reliable results is known as the procedure for determining "air-filled pore space levels" in container media used in horticulture. In this technique, samples of known bulk density are

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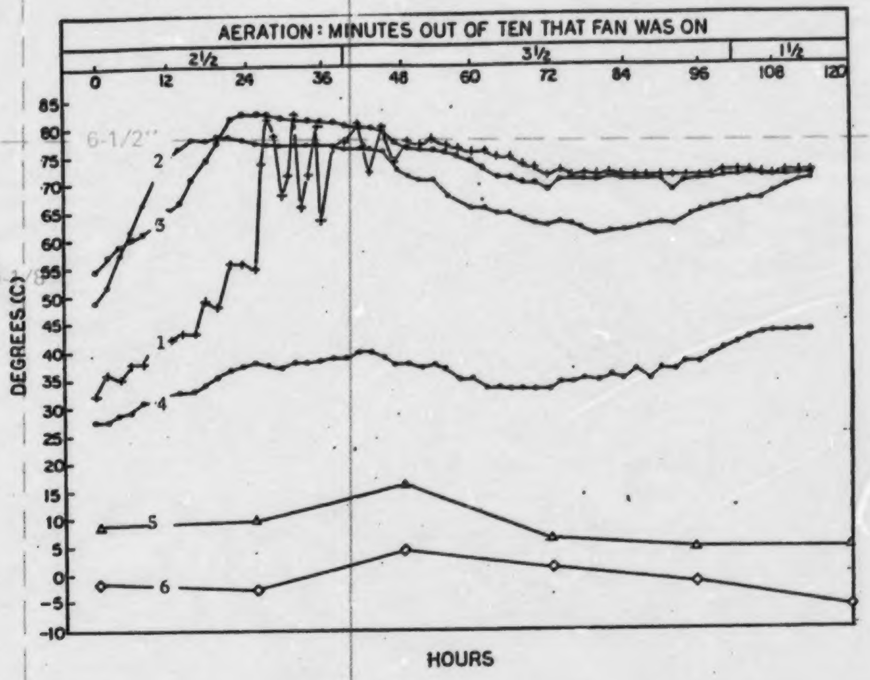

Fig. 6. Temperature at various depths from surface in compost during a winter trial (2/26/81-3/3/81) with anaerobically digested sludge after the second turn: 1, 2, 3 and 4 are 7.5, 90, 150, 245 cm from the surface, respectively. 5 and 6 are daily ambient maximum and minimum temperatures, respectively.

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TABLE 10 . Mean percent volatile solids distribution in the reactor after 34 days of composting for a winter trial.

Depth (cm from surface)	Distance from wall (cm) 15	150	230	300	380	460	580	Means for depth[1]
7.5	71.2[2]	70.4	73.6	67.7	74.0	69.2	66.3	
15	69.5	68.7	70.4	71.5	73.4	70.0	66.7	70.3
60	70.0	69.2	70.6	69.9	72.6	70.5	68.1	70.1
120	70.0	71.0	70.6	67.9	69.5	68.9	66.6	70.1
150	69.8	70.1	70.2	70.2	72.2	73.3	69.0	69.5
210	58.3	62.5	64.2	61.9	67.0	64.0	62.5	70.7
245	56.7	60.0	61.1	62.0	60.2	58.1	57.1	62.9
								59.1
Mean for distance from wall[3]	66.5	67.3	68.7	67.2	69.9	67.7	65.5	

[1] Means (of 14 samples) joined by common line are not significantly different according to Duncan's new multiple range test. LSD .05=2.9.

[2] Means of two samples.

[3] Means of 14 samples, no significant differences (P=.05).

packed to the appropriate density in a 1 liter glass graduate cylinder. It is accurate for batches of composts of known bulk density. Since reactor feed and product for seven trials in 1982 and 1983 were weighed and total volumes in the reactor could be determined accurately, precise bulk density values were available. After the weights of the empty and packed cylinder were determined, water was allowed to drain via a tube along the inside wall of the cylinder to the base of the cylinder where air was forced upwards, as water entered. Water was added during a 10 min period while the sidewalls of the cylinder were tapped with a rubber stopper. Addition of water was stopped once the surface of the compost glistened. All air bubbles were removed from the compost in this fashion. The compost used in this work did not float in water. Sludge particles did not rearrange during the 10 min time period. The cylinder was then reweighed and the increase in weight of the cylinder contents represented the volume of air replaced by water and was used to calculate percent Free Air Space. Compost samples, which were drier than 35% moisture did not wet well when water was added. Air pockets could be seen in the vessel. To avoid this a wetting agent was added to the water which removed air from the dry sample. Means were calculated from a minimum of three samples.

Chemical analyses. Total Kjeldahl nitrogen, total organic carbon, carbon-nitrogen ratio and pH of reactor feed and product were determined on three samples per treatment by T. J. Logan, Professor, Department of Agronomy, Kottman Hall, OSU, Columbus, OH. Conductivity in a saturated paste extract, pH, total N, P, and K, as well concentrations of heavy metals were determined on cured compost of seven trials by the sludge laboratory of the Research Extension and Analytical Laboratory (REAL) of OSU, OARDC, Wooster, OH 44691.

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PAGE NUMBER
EPA Form 2350-4 (4-80)
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MATERIALS BALANCES FOR SEVEN COMPOSTING TRIALS

Introduction. Several parameters were examined in seven composting trials performed from October 15, 1982 to Aprl 10, 1983. Factors affecting the rate of composting and drying were evaluated. In trials I and II, the effect of process temperature on the composting process was examined. Trial I basically served to test all equipment. Attempts were made to maintain high (mean of 63 C) and low (mean of 43 C) temperatures throughout each trial. In trial III and IV the effects of a high process temperature early in the composting process followed by a low temperature later in the process were compared with the reverse of these temperature regimes. The purpose of these trials was to establish whether reduction in fecal pathogens could be accomplished early and/or late in the process. In trial V the effect of blending reactor feed with a pugmill mixer on the rate of composting was compared with that of front-end-loader (FEL) mixing. In trial VII high and low process temperatures were combined with reverse airflow to expose compost in the bottom of the vessels to high temperatures. From January to October 1982, 10 composting trials were performed by Compost Systems Co., 9403 Kenwood Rd., Cincinnati, OH 45242 under a City of Akron, EPA grant to Burgess and Niple, Limited, 46 South Summit St., Akron, OH. The testing laboratory was used during these trials and the general procedures used to determine a materials balance were based on sampling methods developed during preliminary trials. As a result of this work, a summary of which is presented in Appendix III, a data base was established for composting of municipal sludge in the Paygro reactor.

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Materials balance. Detailed materials balances of trials I-VII are presented in Tables 11-17. The mean percentage dry solids (% DS) of the sludges received from the City of Akron used in these trials was 21.6 (Table 18). Raw primary sludge was used in all trials, except in trial VI, for which a mixture of primary and waste-activated sludge was used.

The top 30-40 cm layer of the reactor product usually was higher in moisture content than the lower part. Therefore the top layer was removed separately and placed into a curing pile. The bottom layer in the reactor product was recycled into the following trial as bulking agent. It is referred to as "recycled compost" in this report. The mean % DS of the recycled compost in these trials was 58.6 (Table 18). Bark and sawdust made up the remainder of the bulking agent with % DS values of 53.9 and 50.0 respectively.

Sludge, bark, sawdust and recycled compost were mixed at a volumetric ratio of 1.0, 0.4, 0.3, and 2.8, respectively, to yield 46.3% DS in the reactor feed. The mean % DS of the reactor product, which was moved to the curing piles, was 53.0. The overall % DS of the reactor product after 16.0 days of composting was 56.9. The mean percentage volatile solids (% VS) for each component is also listed in Table 18.

Decomposition rates as measured by 1) CO_2 evolution, 2) loss in weight of dry solids per trial and 3) by a reduction in % VS, varied from trial to trial. The mean ambient high and low temperatures were 9.9 and 3.0 C. Means of water loss and volatile solids destruction for trials I-VII are presented in Table 19. The mean percentages loss in wet weight and dry solids were 25.7 and 9.3, respectively during a mean of 16 days of composting. During this time period the mean percentage of water evaporated

TABLE 11 MATERIALS BALANCE FOR TRIAL I. COMPOST RETENTION TIME = 12.6 DAYS. VOLUME OF REACTOR FEED = 473 CUBIC YARDS.

COMPONENT	WET WT (LBS)	% SOLIDS	WT SOLIDS (LBS)	WT WATER (LBS)
RECYCLE	329,920	67.4	222,366	107,554
BARK	33,000	57.0	18,810	14,190
SAWDUST	31,680	56.0	17,741	13,939
SLUDGE	316,520	22.0	69,634	246,886
TOTALS	711,120	46.2	328,551	382,569
	53,503[1]			
REACTOR FEED	657,617	46.2	303,819	353,798
REACTOR PRODUCT[2]	438,460	61.9	271,407	167,053
RECYCLE	367,790	62.1	228,516	139,464
CURING	70,480	61.9	43,627	26,853
DESTROYED	219,157		32,412	186,745

[1] EXCESS MATERIAL NOT PLACED IN REACTOR

[2] REACTOR PRODUCT USED IN SUBSEQUENT TRIALS DESIGNATED AS RECYCLE WITH REMAINDER PLACED IN CURING PILE

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TABLE 12. MATERIALS BALANCE FOR TRIAL II. COMPOST RETENTION TIME = 14.75 DAYS. VOLUME OF REACTOR FEED = 473 CUBIC YARDS.

COMPONENT	WET WT (LBS)	% SOLIDS	WT SOLIDS (LBS)	WT WATER (LBS)
RECYCLE	367,980	62.1	228,516	139,464
BARK	48,580	48.4	23,513	25,067
SAWDUST	28,560	61.1	17,450	11,110
SLUDGE	289,920	19.0	55,085	234,835
TOTALS	735,040	44.2	324,888	410,152
REACTOR FEED	735,040	44.2	324,888	410,152
REACTOR PRODUCT[1]	535,800	56.4	301,986	223,814
RECYCLE	437,000	57.8	252,586	184,414
CURING	98,800	50.0	49,400	49,400
DESTROYED	199,240		22,902	186,338

[1] REACTOR PRODUCT USED IN SUBSEQUENT TRIALS DESIGNATED AS RECYCLE WITH REMAINDER PLACED IN CURING PILE

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TABLE 13. MATERIALS BALANCE FOR TRIAL III. COMPOST RETENTION TIME = 15 DAYS. VOLUME OF REACTOR FEED = 673 CUBIC YARDS.

COMPONENT	WET WT (LBS)	% SOLIDS	WT SOLIDS (LBS)	WT WATER (LBS)
RECYCLE	437,000	57.8	252,586	184,414
(AKR #8)	108,720	60.0	65,232	43,488
BARK	32,080	65.3	20,948	11,132
SAWDUST	32,340	59.6	19,275	13,065
SLUDGE	297,280	19.1	56,780	240,500
TOTALS	907,420		414,821	492,599
REACTOR FEED	907,420	45.7	414,821	492,599
REACTOR PRODUCT[1]	716,780	55.4	397,096	319,684
RECYCLE	541,540	57.5	311,386	230,154
CURING	175,240	48.9	85,710	89,530
DESTROYED	190,640		17,725	172,915

[1] REACTOR PRODUCT USED IN SUBSEQUENT TRIALS DESIGNATED AS RECYCLE WITH REMAINDER PLACED IN CURING PILE

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TABLE 14. MATERIALS BALANCE FOR TRIAL IV. COMPOST RETENTION TIME = 20.25 DAYS. VOLUME OF REACTOR FEED = 663 CUBIC YARDS.

COMPONENT	WET WT (LBS)	% SOLIDS	WT SOLIDS (LBS)	WT WATER (LBS)
RECYCLE	541,540	57.5	311,386	230,154
AKR III	27,840	74.8	20,824	7,016
AKR X	27,340	66.1	18,072	9,268
BARK	51,880	54.0	28,015	23,865
SAWDUST	39,380	47.4	18,666	20,714
SLUDGE	249,300	18.5	46,121	203,179
TOTALS	937,280	47.3	443,089	494,195
REACTOR FEED	937,280	47.3	443,084	494,195
REACTOR PRODUCT[1]	709,860	53.5	379,775	330,085
RECYCLE	535,080	53.7	287,338	247,742
CURING	174,780	53.2	92,983	81,797
DESTROYED	227,420		63,309	164,110

[1] REACTOR PRODUCT USED IN SUBSEQUENT TRIALS DESIGNATED AS RECYCLE WITH REMAINDER PLACED IN CURING PILE

TABLE 15. MATERIALS BALANCE FOR TRIAL V. COMPOST RETENTION TIME = 21.7 DAYS. VOLUME OF REACTOR FEED = 581 CUBIC YARDS.

COMPONENT	WET WT (LBS)	% SOLIDS	WT SOLIDS (LBS)	WT WATER (LBS)
RECYCLE	535,080	53.7	287,338	247,742
BARK	45,280	50.0	22,640	22,640
SAWDUST	45,000	47.0	21,150	23,850
SLUDGE	187,740	21.2	39,801	147,939
TOTALS	813,100	45.6	370,929	442,171
	64,080[1]			
REACTOR FEED	749,080	45.6	341,580	407,500
REACTOR PRODUCT[2]	579,820	53.22	308,580	271,240
RECYCLE	388,740	53.91	209,570	179,170
CURING	191,080	51.83	99,010	92,070
DESTROYED	169,260		33,000	136,260

[1] EXCESS MATERIAL NOT PLACED IN REACTOR

[2] REACTOR PRODUCT USED IN SUBSEQUENT TRIALS DESIGNATED AS RECYCLE WITH REMAINDER PLACED IN CURING PILE

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TABLE 16. Materials balance for Trial VI. Compost retention time = 15.3 days. Volume of reactor feed = 473 cubic yards.

Component	Wet wt (lbs)	% Solids	Wt solids (lbs)	Wt water (lbs)
Recycle	388,740	53.9	209,570	179,170
Bark/sawdust	83,920	51.6	43,336	40,584
Sludge	165,800	27.2	45,116	120,684
Totals	638,460		298,022	340,438
Reactor feed	638,460	46.7	298,022	340,438
Reactor product[1]	498,400	56.4	280,936	217,464
Recycle	381,560	58.1	221,760	159,000
Curing	116,840	50.7	59,176	57,664
Destroyed	140,060		17,086	122,974

[1] Reactor product used in subsequent trials designated as recycle with remainder placed in curing pile.

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TABLE 17. Materials balance for Trial VII. Compost retention time = 12.6 days. Volume of reactor feed = 473 cubic yards.

Component	Wet wt (lbs)	% Solids	Wt solids (lbs)	Wt water (lbs)
Recycle	381,560	58.1	221,760	159,800
Bark/sawdust	87,760	51.7	45,387	42,373
Sludge	166,240	23.9	39,765	126,475
Totals	635,560		306,912	328,648
	34,740[1]			
Reactor feed	600,820	48.3	290,137	310,683
Reactor product	442,700	57.6	254,983	187,717
Destroyed	158,120		35,154	122,966

[1] Excess material not placed in reactor.

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Table 18. Mean dry solids (% DS) and volatile solids (% VS) of components, reactor feed and reactor product for seven composting trials. Mean compost retention time = 16.0 days.

Component	% DS	% VS	Volume ratio
Sludge	21.6	58.9	1.0
Bark	53.9	86.5	.4
Sawdust	50.0	95.0	.3
Recycle	58.6	57.0	2.8
Reactor Feed	46.3	58.9	
Reactor Product	56.9	56.3	

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TABLE 19. Percentage loss of wet weight, weight dry solids and weight water: Number of days retention and mean high and low ambient air temperatures for compost Trials I-VII.

	Trial							Mean
	I	II	III	IV	V	VI	VII	(I-VII)
% Loss in:								
Wet Weight	33.3	28.2	21.0	24.3	22.6	21.9	26.3	25.7
Weight Dry solids	10.4	8.5	4.1	14.5	9.7	5.7	12.1	9.3
Weight water	52.9	43.7	35.3	33.0	33.5	36.1	39.6	39.2
Days Retention	12.6	14.8	15.0	20.3	21.7	15.3	12.6	16.0
Mean temperature (C) of ambient air								
High	24.8	12.5	7.3	3.7	1.0	12.2	7.5	9.9
Low	14.1	4.7	3.3	-3.7	-1.5	2.9	1.2	3.0

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was 39.2. This loss in water does not include water liberated through biological activity. A limited attempt was made to determine a water balance for the system. Direct measurements were not possible within the scope of this study, therefore, only calculations of biological water liberated based on stoichiometric formulae and loss in dry solids can be made.

Air flow through the compost (CFM) changed markedly over the course of a given trial. Rates were lowest (1,000-1,500 CFM) at the beginning of a trial when the % solids was lowest. After the compost was turned the highest rates (2,000-3,200 CFM) were observed. Static head pressures varied at any given time among sections and with time within sections. The static head pressure measured just past the fan, where air entered the plenum under the reactor, ranged from 1.5-2.0 inches of water when reactor vessels were empty. Static head pressures (inches of water) for fully loaded vessels ranged from 5-7 inches. Readings were generally lowest after turning (as low as 4"). Increases occurred thereafter as compost settled (from the full height of 290 cm to as low as 240 cm).

Results of chemical analyses of the reactor product of all seven trials indicated that heavy metals were not being concentrated with the bulking agent ratios used in these trials. The percent nitrogen (T.K.N.) ranged from 1.7-2.0 with the greater portion (1.3-1.8%) existing as organic nitrogen. There was no appreciable change in pH (7.0-7.5) or increase in conductivity (6.8-11.0 MMHOS) in the reactor product.

Pugmill mixing versus FEL mixing of reactor feed. In trial V a Speedflow pugmill mixer was tested for the Paygro system. The reactor feed was mixed by FEL and part of it was then fed through the pugmill during the

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tank loading process. Two sections were filled with reactor feed produced by each of the two procedures. Mean % FAS (free air space) readings in the FEL sections were significantly ($P=0.05$) higher (45.2) than those in the pugmill-mixed sections (42.3) at the beginning of the trial. After 21.5 days when the reactor product was removed the mean % FAS values in the FEL and pugmill sections were significantly lower (42.6 and 38.5 respectively). In spite of higher FAS readings in the FEL-mixed sections, airflow was higher in pugmill sections. Rates of airflow in the FEL sections ranged from 1000-2000 CFM whereas airflow in the pugmill sections were 2000-3000 CFM.

Samples of the reactor feed were removed from both sections before the first turn. In the FEL-mixed sections "balls" of sludge were found. After the sludge balls were cut in half putrifactive odors escaped. No bulking agent was present inside these sludge balls. In the pugmill-mixed sections balls also were found. However when these were broken open, putrifactive odors were not detected and bulking agent was present uniformly throughout. The low airflow rates in the FEL-mixed sections therefore may have been due to the presence of "flattened" sludge balls in the base of the reactor, thus decreasing % FAS and restricting airflow in that area, resulting in some anaerobic metabolism.

Rates of drying for the two treatments are presented in Table 20. After the first turn (14 days) the % DS of the compost in the speedflow section was significantly higher ($P=0.01$) than that in the FEL section after 21 days. Drying therefore was significantly better in the pugmill-mixed sections than in the FEL-mixed sections. Data on CO_2 evolution were not obtained in this mid-January trial since ice accumulated in lines (ahead of the condensor) and interfered with airflow to the CO_2 analyzer.

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TABLE 20. DRY SOLIDS (%) OBTAINED IN TRIAL V USING FRONT END LOADER (FEL) AND PUGMILL MIXER (SPEED FLOW).

	METHOD OF MIXING	
	FEL	SPEED FLOW
REACTOR FEED	46.21	47.4
TURN (14 DAYS RETENTION)	50.5	54.6**
REACTOR PRODUCT (21 DAYS RETENTION)	52.7	58.8**

LSD (P = .01) = 3.48

** DIFFERENCES BETWEEN MIXING TREATMENTS ARE SIGNIFICANT (P = .01)

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SPECIFIC ACTIVITY OF THE COMPOST BIOTA

MacGregor et al. (11) found that low process temperatures appeared to favor CO_2 production and drying during composting. In a preliminary summer trial during 1981 similar observations were made with the Paygro System. However measurements on actual amounts of air forced through the compost piles and therefore measurements on actual levels of CO_2 produced were lacking in both studies.

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In trials II and VII carbon dioxide evolution was measured for sections of the reactor maintained at "low" (40 C) and "high" (60 C) temperatures. Temperature was controlled by regulating the amount of air entering each section. In trial II a continuous flow was maintained and the volume of air varied by opening or closing gates. The total weight of carbon dioxide evolved during this trial was abnormally high and did not correspond to the calculated weight of carbon dioxide lost based on measured losses of dry solids. These calculations assumed that glucose was the primary carbon source metabolized and thus each kg of dry solids yielded approximately 1.5 kg carbon dioxide. However there were appreciable differences in the weights of carbon dioxide evolved from the "hot" and "cool" sections which corresponded to the differences in losses of dry solids and volatile solids. Thus the amounts of carbon dioxide produced during trial II were expressed as arbitrary quantitative units.

CO_2 evolution and airflow for the "hot" and "cool" sections in trial II, as well as mean temperatures and the percent of reactor volume above 55

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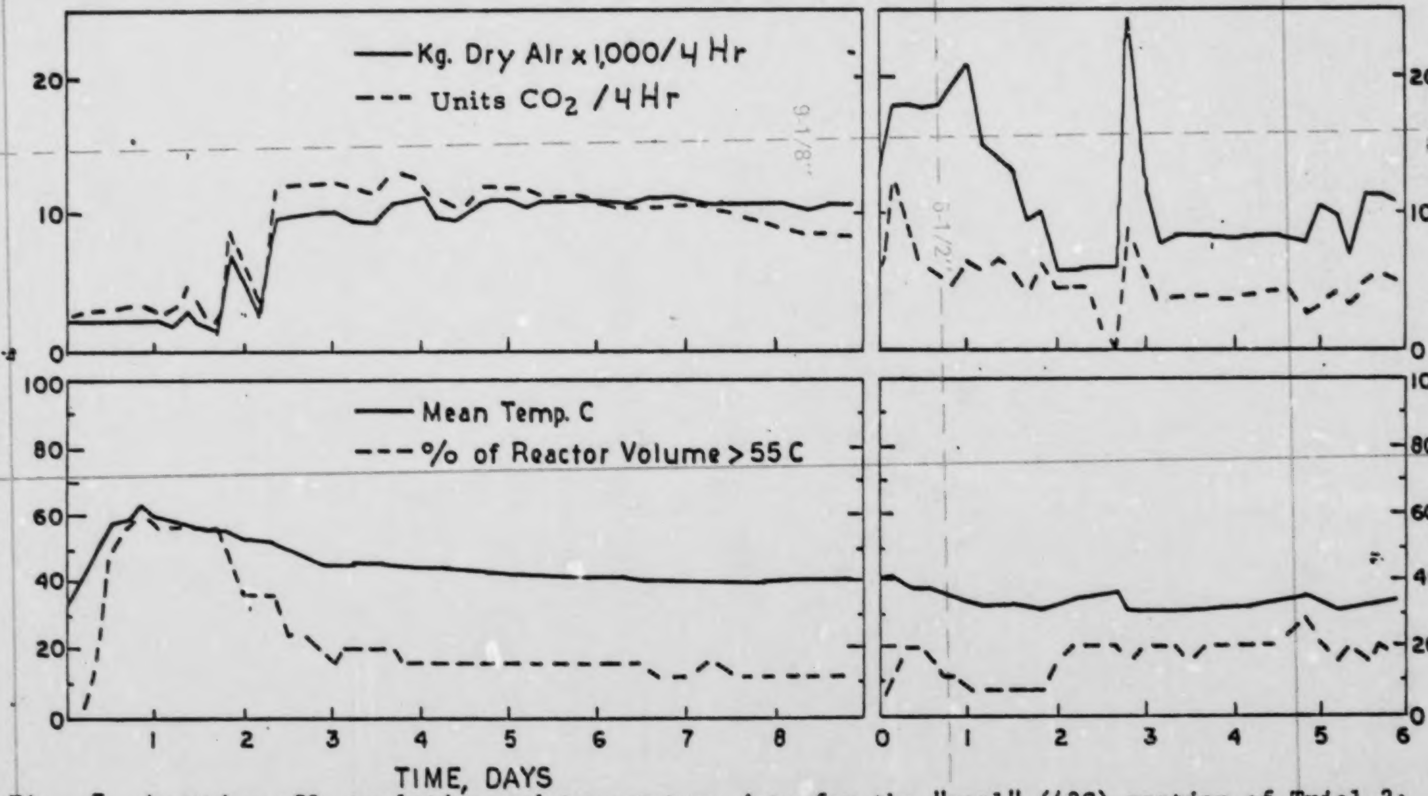

Fig. 7. Aeration, CO_2 evolution and temperature data for the "cool" (43C) section of Trial 2: Aeration and CO_2 evolution are given for each 4 hour interval. Mean temperature and % of Reactor Volume > 55C are based on readings from 20 thermocouples. The compost was turned once after 9 days and removed from the reactor 6 days later.

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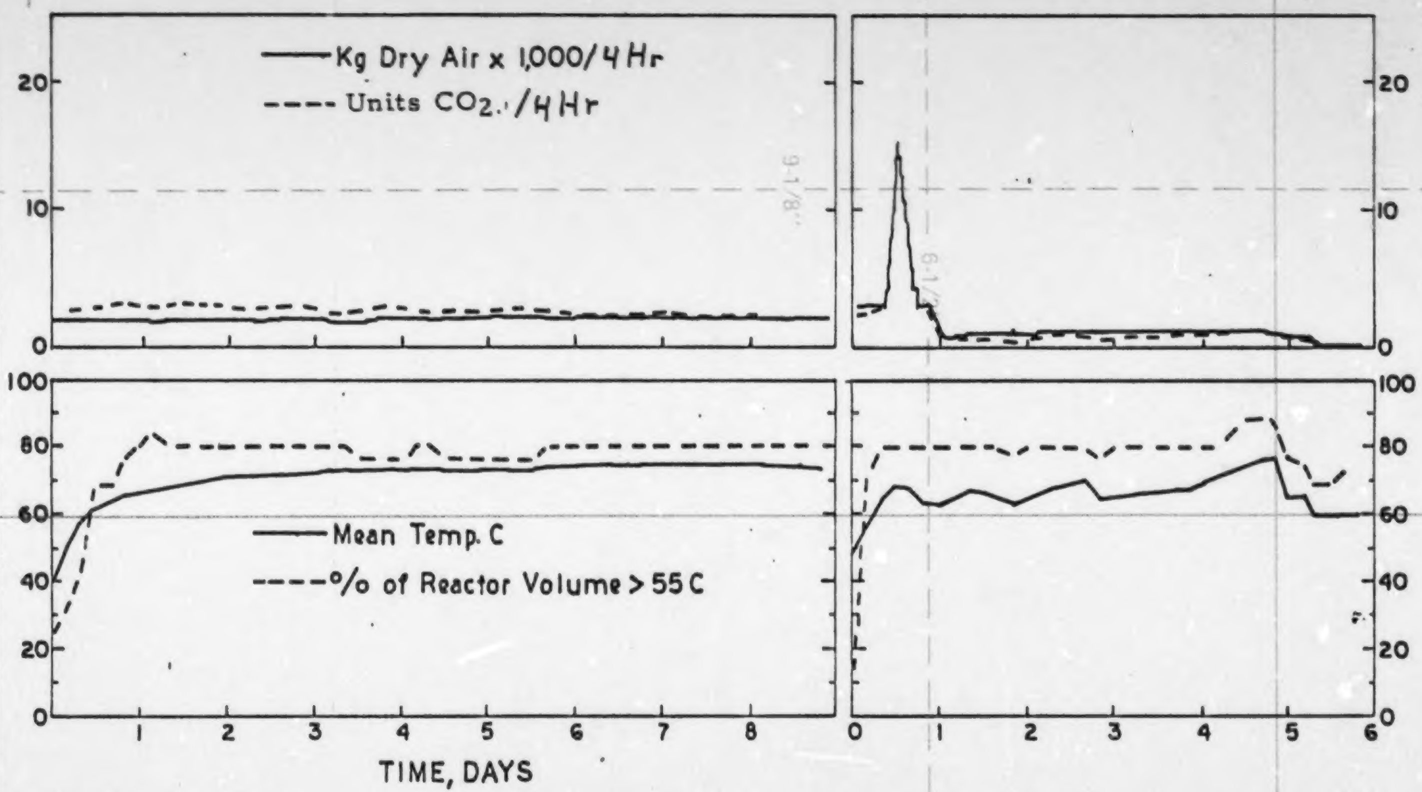

Fig. 8. Aeration, CO_2 evolution and temperature data for the "hot" (65C) section of Trial 2. Aeration and CO_2 evolution are given for each 4 hour interval. Mean temperature and % of Reactor Volume > 55C are based on readings from 20 thermocouples. The compost was turned once after 9 days and removed from the reactor 6 days later.

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C, are presented in Figs. 7 and 8. The highest levels of CO_2 evolution and airflow occurred in the "cool" section. Mean temperature and % volume above 55C appeared to be negatively correlated with CO_2 evolution and airflow. The highest level of CO_2 evolution in the "cool" section occurred within a temperature range of 38-55 C (Fig. 9). Levels of CO_2 evolution before the turn were considerably higher than those after the turn.

In trial VII temperatures were controlled by automatically turning the fans on or off when the mean temperature reached or fell below a set value. As observed in trial II, "cool" sections dried more rapidly and lost more volatile solids than "hot" sections. As shown in Table 21, there already were significant differences (P=0.05) between sections in the percent dry solids by the time the compost was turned (5.6 days). Differences in the percent volatile solids between sections were not evident until the end of the trial (12.6 days). In addition, differential rates of activity between "cool" and "hot" sections were evident when the percent losses of dry solids were compared. Approximately 15% of the dry solids of the reactor feed was lost in 12.6 days in the "cool" section in contrast to only 10% in the "hot" section.

The relationships between air volumes, carbon dioxide evolution, mean temperature and % of compost >55 C are shown in Figs. 10-13. Before the turn, the mean temperatures in the "cool" sections were maintained between 36 and 46 C (Fig. 10) whereas the mean temperatures in the "hot" sections were held to between 50 and 86 C (Fig. 12). After the turn (day 6.6-13.3), the temperatures in the "cool" sections were maintained at 32-36 C (Fig. 11). Mechanical problems with one of the fans in one of the "hot" sections resulted in poor temperature control after day 9 (Fig. 13). Differences in

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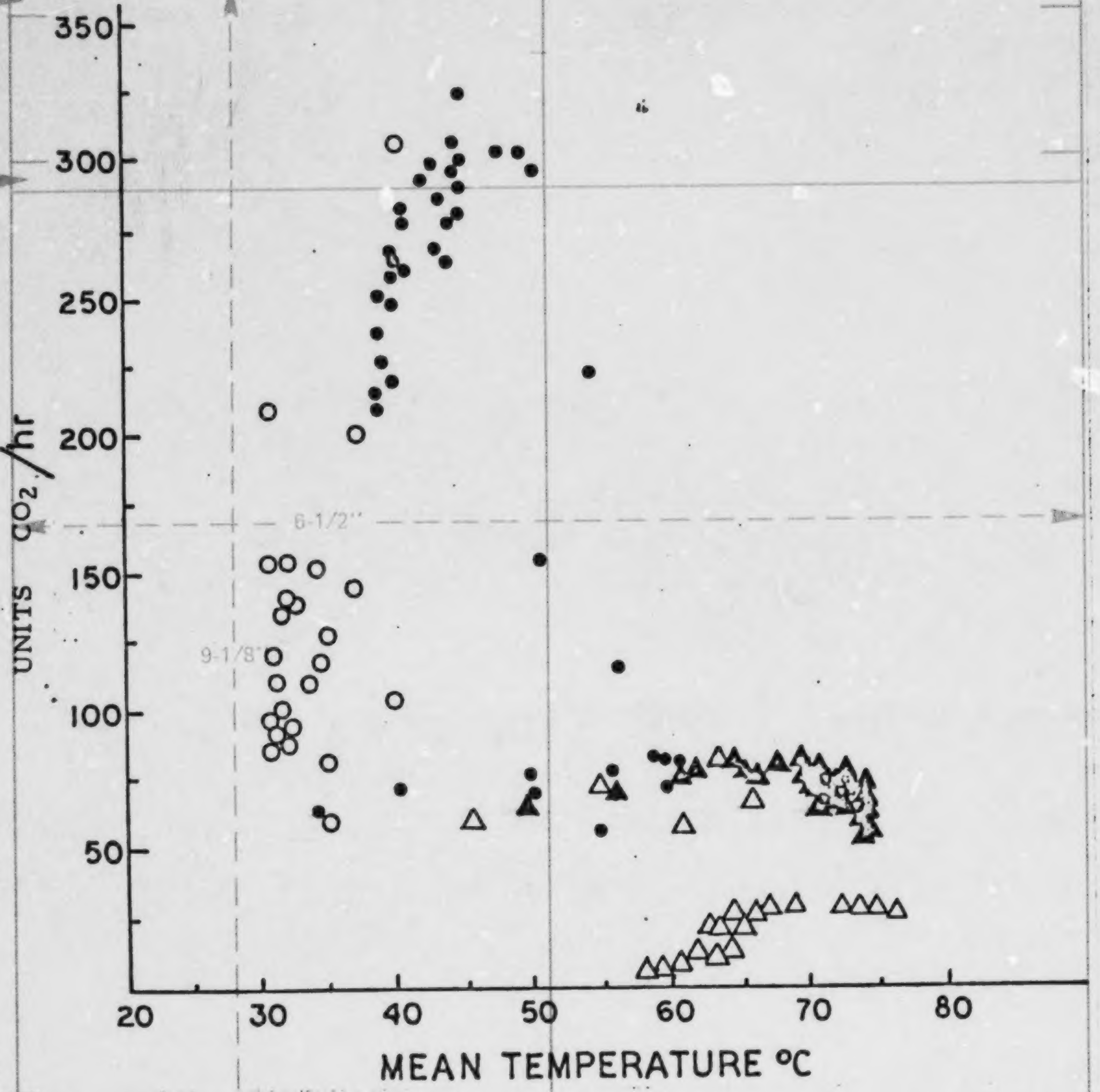

Fig. 9. Relationship between CO_2 evolution and mean compost temperature in trial II. ● ="cool" section before turn, O="cool" section after turn, ▲ ="hot" section before turn, △ ="hot section after turn.

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Table 21. Percent dry solids (% DS), percent volatile solids (% VS) and percent loss of initial weight of dry solids for "cool" and "hot" sections of trial VII

	% DS		% VS		% Loss of initial weight DS	
	"Cool"	"Hot"	"Cool"	"Hot"	"Cool"	"Hot"
Reactor Feed	48.2	48.3	57.4	59.4	---	---
Turn (5.6 days)	54.9	52.3*	59.4	59.2	8.6	5.3
Reactor Product (12.6 days)	60.8	55.4**	55.5	59.6*	14.8	10.0

* Difference between "cool" and "hot" sections significant at P=.05

** Difference between "cool" and "hot" sections significant at P=.01

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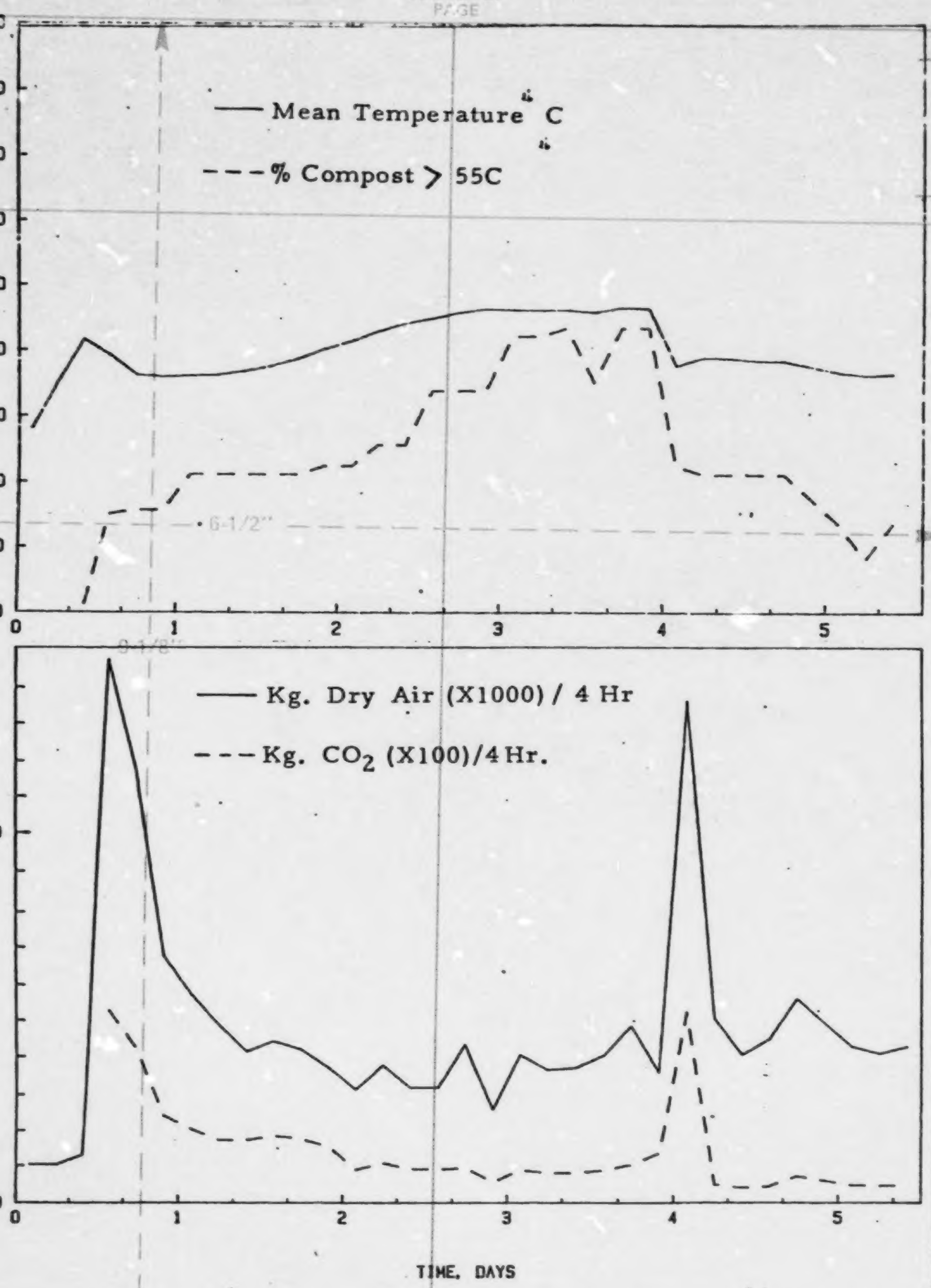

Fig. 10. Aeration, CO_2 evolution, and Temperature data for "cool" section of reactor before first turn in Trial VII.

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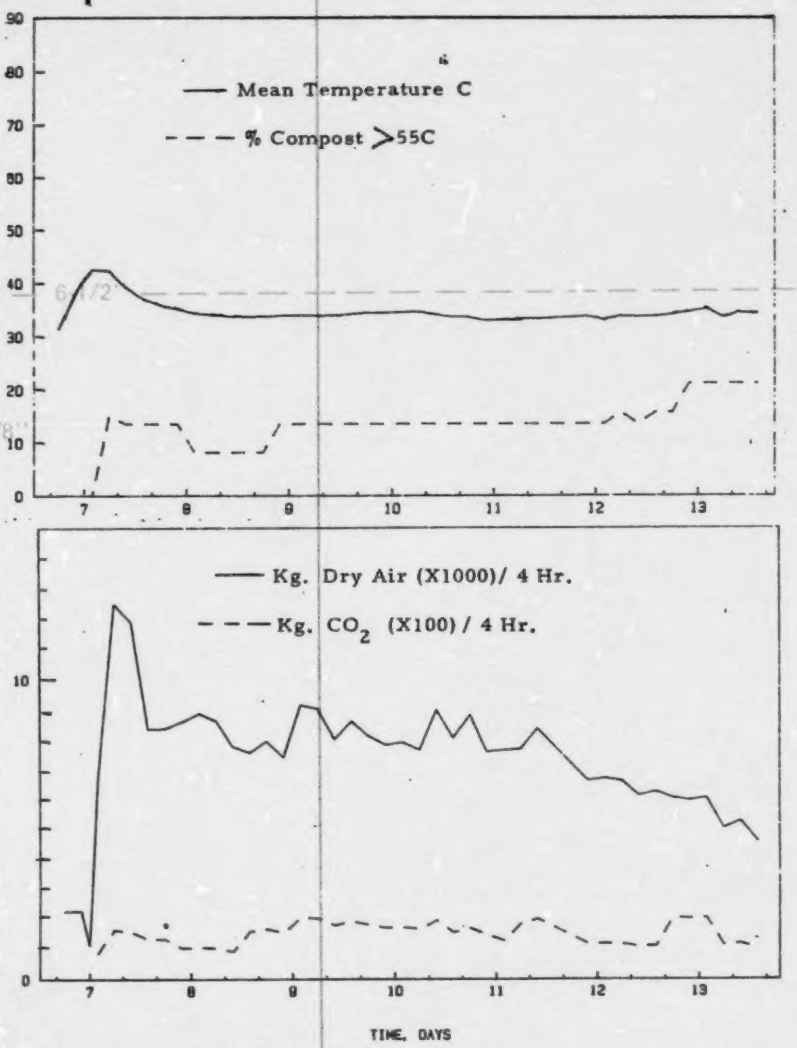

Fig. 11. Aeration, CO_2 evolution and temperature data for "cool" section of reactor after turn in Trial VII.

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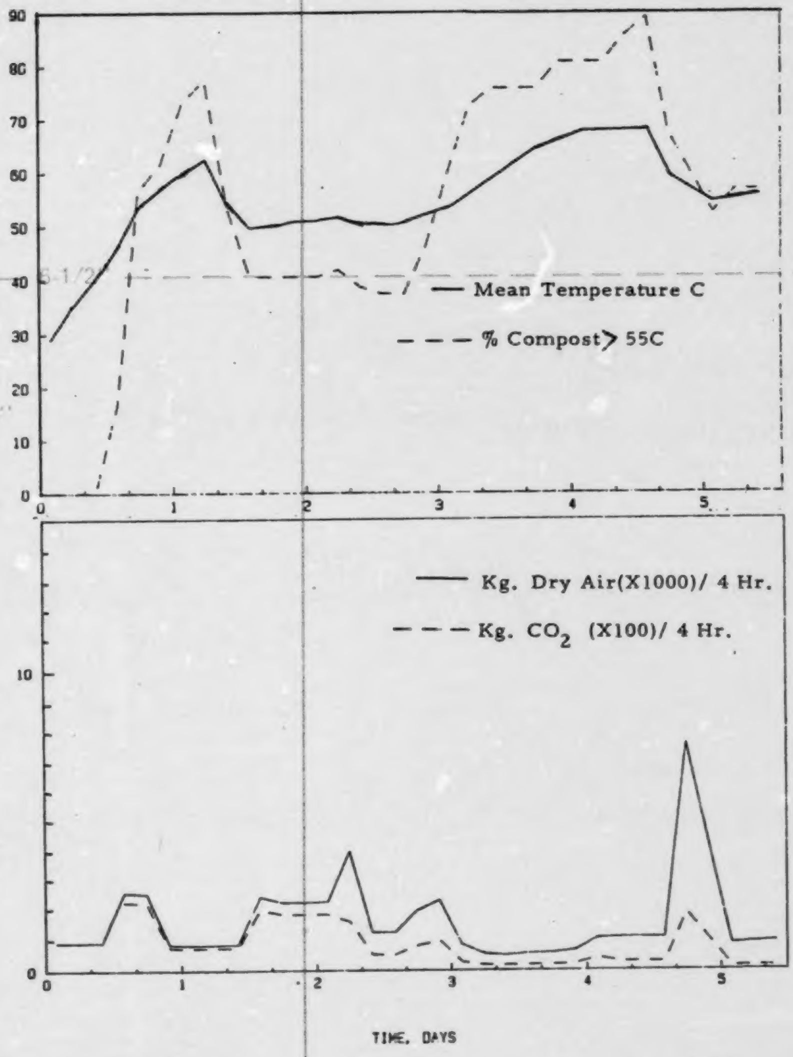

Fig. 12. Aeration, CO_2 evolution and temperature data for "hot" section of reactor before turn in Trial VII.

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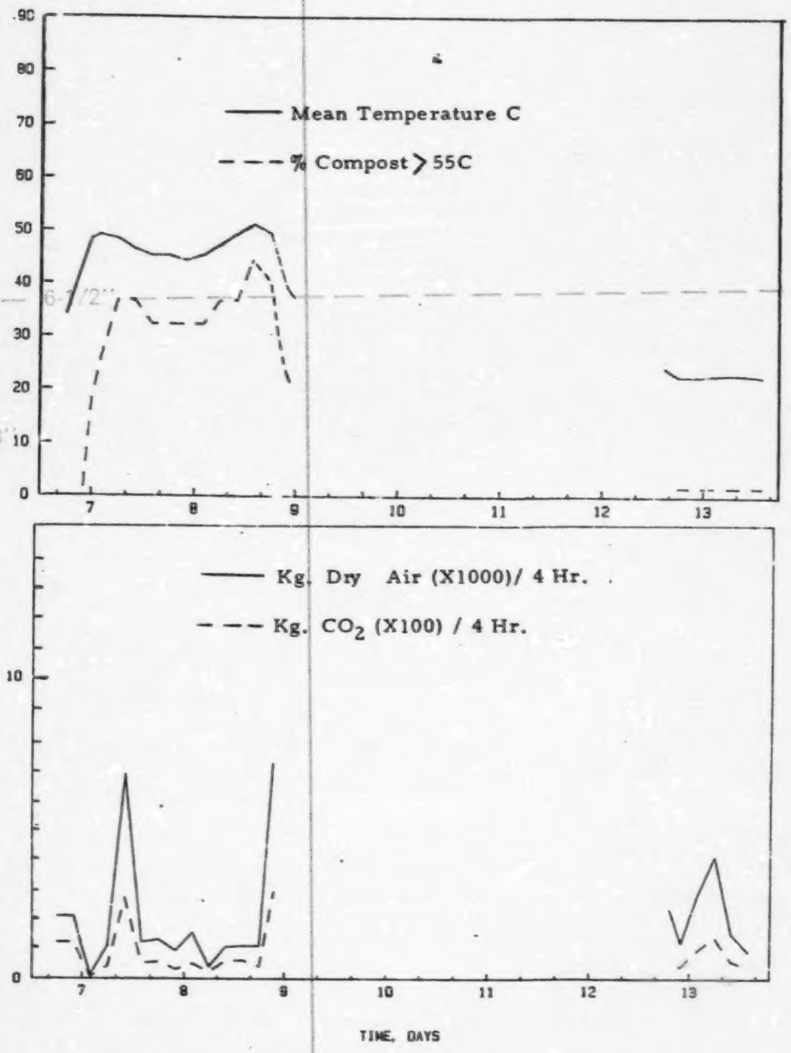

Fig. 13. Aeration, CO_2 evolution and Temperature data fot "hot" section of reactor after turn in Trial VII.

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the mean temperatures and % of compost >55 C were due to differences in the amounts of air supplied to the sections. Air was forced through "cool" sections at 14,000-2500 kg dry air/4 hr and through "hot" sections at 7500-500 kg dry air/4 hr. During the period of mechanical failure it was assumed that the air flow through the "hot" section from the adjacent "hot" section was 500 kg dry air/4 hr. Readings of the percent carbon dioxide were available throughout this period and calculations of carbon dioxide evolved were based on this assumption.

Within each section variations in mean temperature during the trial were principally due to variations in amounts of air supplied. For example, in the "cool" section between day 1 and 4 airflow was reduced from 14,500 kg to 2500 kg dry air/4 hr (Fig. 10). During this period the mean temperature increased slowly. The mean temperature was next reduced sharply on day 4 by increasing airflow. After the turn, temperature was maintained at a nearly constant level from day 8 through 13 (Fig. 11). The amount of air supplied during this period declined steadily. This reduction in air may have been due to reduced microbial activity and thus heat output due to gradual depletion of the most readily available energy sources over this time period. However during this period there was a drop in ambient temperature which may also have been partially responsible for this trend.

The amount of carbon dioxide evolved each 4 hour interval was generally higher in the "cool" section than in the "hot" section. In addition, in both "cool" and "hot" sections carbon dioxide evolution was greatest at the beginning of the trial and tended to decline with time. For example in the "cool" section amounts declined from 250 to 50 kg CO_2/4 hr from day 0.6 to day 6 (Fig. 10). This drop in CO_2 evolution appeared to be independent of variations in the volume of air supplied during this period and was the result of a decrease in the percent CO_2 values measured. The decline in carbon dioxide evolution from day 1 to 4 corresponds with an increase in the mean temperature and percent of the compost >55C. After the turn the amounts of CO_2 evolved in the "cool" section were greater than those observed immediately prior to the turn. This difference reflects lower temperatures during this time and possibly the release of available nutrients as a result of the turning process.

The measured weight of carbon dioxide lost (metric tons) from the "cool" and "hot" sections corresponded closely to the calculated losses assuming glucose as the primary carbon source (Table 22). Values based on the stoichiometric formula (1) for sludge did not correspond as closely. Thus for this trial the air measurement data and carbon dioxide measurements appear to be accurate and therefore, meaningful calculations of the overall respiration rates for this system can be made.

For comparison with other studies the measured rates of carbon dioxide evolution (kg/4 hr) were converted to mg CO_2/g VS-hr (Table 23). Rates of CO_2 production in the Paygro system for the 108 m^3 "cool" sections ranged from 5.9 mg CO_2/g VS-Hr at the beginning of the trial to 0.6 mg CO_2/g VS-Hr just before the turn. In the "hot" section these rates were much lower. Also oxygen uptake rates were calculated (mg O_2/g VS-Hr) for selected times during trial VII (Table 23). Rates of oxygen uptake were based on the assumption that glucose was the primary source of carbon and that aerobic respiration prevailed. These values are very similar to rates published for various pilot-scale composting systems as shown in Fig. 14 (from Haug, R. T., Compost Engineering, Principles and Practice, Ann Arbor Science, Ann Arbor, MI. p. 316, Fig. 7).

Table 22. Comparison between carbon dioxide evolution values and calculated values based on stiochiometric formulae for trial VII

Time Period	Section	Observed loss of CO_2 (metric tons)	Measured loss of dry solids (metric tons)	Calculated weight of CO_2 for equal weight loss of:[1] Sludge (metric tons)	Glucose (metric tons)
Before turn	"Cool"	4.2	3.3	7.2	4.9
	"Hot"	2.5	2.0	4.4	3.0
After turn	"Cool"	5.6	2.4	5.3	3.5
	"Hot"	2.6	1.6	3.5	2.4
Total	"Cool"	9.8	5.7	12.5	8.4
	"Hot"	5.1	3.6	7.9	5.4

---

[1] Stiochiometric calculations based on the following formulae:

Sludge: $C_{10}H_{19}O_3N + 12.5\ O_2 \longrightarrow 10\ CO_2 + 8H_2O + NH_3$

Glucose: $C_6H_{12}O_6 + 6O_2 \longrightarrow 6\ CO_2 + 6H_2O$

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Table 23. Carbon dioxide production and oxygen uptake determinations for "cool" and "hot" sections of trial VII

Section	Time (HR from start of trial)	Mean temperature	Aeration rates M^3/ton VS-hr [1]	Kg CO_2/ 4 hr	Mg CO_2/ g VS-hr	Mg O_2/ g VS-hr [2]
"Cool"	14	39.3	160	520	5.9	4.3
	122	36.6	51	50	0.6	0.4
"Hot"	14	46.0	30	230	2.6	1.9
	122	54.5	11	10	0.1	0.1

[1] Calculated from measured air volumes (Kg dry air/4 hr).

[2] O_2 calculated on the assumption that glucose is the primary carbon source.

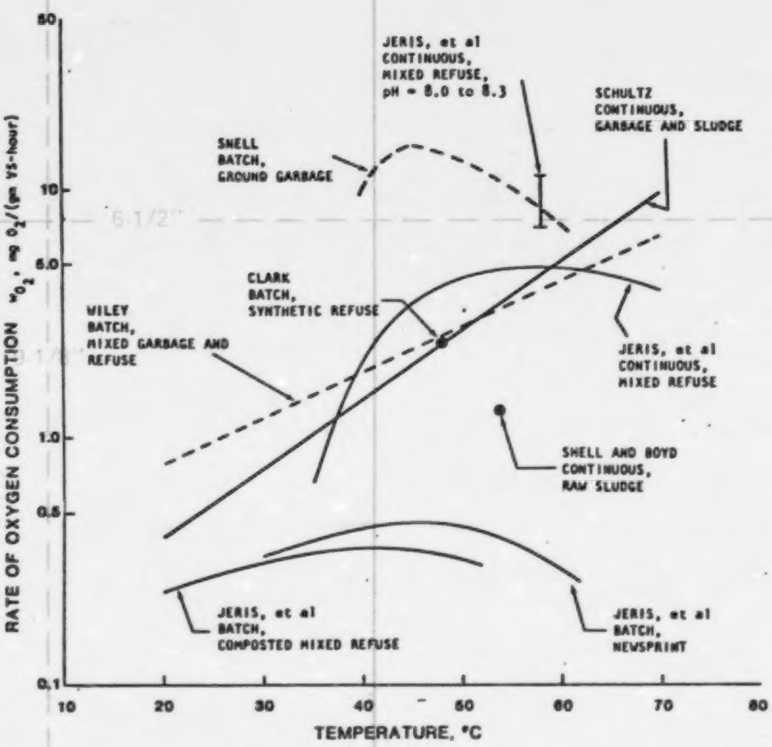

Figure 7. Observed oxygen consumption rates for various composting mixtures and reactor types as a function of temperature. Each curve represents the best fit of observed data.

Fig. 14. From page 316 in Haug R. T., 1980, Compost Engineering. Principles and Practice. Ann Arbor Science. Publishers Inc. The Butterworth Group. P. O. Box 1425, Ann Arbor, MI 48160

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FATE OF FECAL PATHOGENS

Rules and regulations published in Federal Register Vol. 44, #179, Thursday, September 13, 1979, page # 53464 mandate that solid waste composted in within-vessel systems be maintained at operating conditions of 55 C or greater for three days to further reduce pathogens. In one of the preliminary summer trials, in a section maintained at 63 C and turned twice with an 18 day retention time, more than 99% of the compost was exposed to 55 C continuous for three days or more. During normal aeration procedures however, significant vertical and horizontal temperature gradients exist within the Paygro reactor (Fig. 3). Obviously not all compost produced in the Paygro system meets these conditions if it were to be operated without turning and maintained at low (43 C) temperatures by high rates of aeration. For example in trial VII in the "cool" section compost was turned once and only 32% of the compost was exposed to a mean process temperature >55 C for three continuous days. In the "hot" section only 36% met the criteria.

One solution to meeting the 55 C requirement for all sections of the Paygro rector is to reverse airflow. During reverse airflow [negative pressure aeration, (NPA)], heat accumulates in the bottom of the reactor. This could solve the 55 C exposure problem. However during NPA with composts of low percent dry solids, moisture migrates to the base of the reactor resulting in water logging, drainage, poor aeration and problems with freezing in the winter and the production of metabolites of anaerobiosis. All these problems can be avoided by first applying positive pressure aeration (PPA) followed by NPA during the last week of a 3 wk retention time period. These principles were tested at the end of trial VII. After a 12.6 day retention time and one turn with PPA, the compost was turned again and aerated by NPA for 5.6 days followed by an additional 3.5 days of PPA. The total retention time for trial VII therefore was 21.7 days. The mean temperature of the compost and the percentage of the compost <55 C during NPA and PPA are presented in Fig. 15.

During the first 16 hr after the second turn when the compost was incubated without forced aeration temperatures increased gradually (Fig. 16) but were below 40 C. After 16 hr, when NPA was applied (5 min/30 min) a sharp increase in temperature was observed (Fig. 15). After 24 hr (4 hr NPA) temperatures across the entire reactor still were low (24.2-45.1 C with a mean of 33.9 C) but the higher temperatures were located in the bottom center part of the reactor (Fig. 17). No part of the reactor was above 55 C. Aeration was increased to 10 min/30 min after 28 hr (20.00 hr on day 2 in Fig. 15). At the end of that day the mean temperature (65.9 C) stabilized. At this time (52 hr, Fig. 18) 69.8% of the compost was above 55 C. Compost in a large area in the base and center of the reactor was above 80 C. This incubation temperature rapidly kills all known forms of microbial life in compost (3). Temperatures of the compost near the wall in the lower 2 m section also were above 55 C. After this time period, temperatures gradually declined. At 136 hr the weighted mean temperature of the compost was 65 C and 69.8% of the volume was >55 C. The temperature distribution (Fig. 19) was different from that at 52 hr (Fig. 18). Temperatures in the center were lower but higher near the top suggesting that more heat was produced in the cooler top part of the reactor and less in the hot center part.

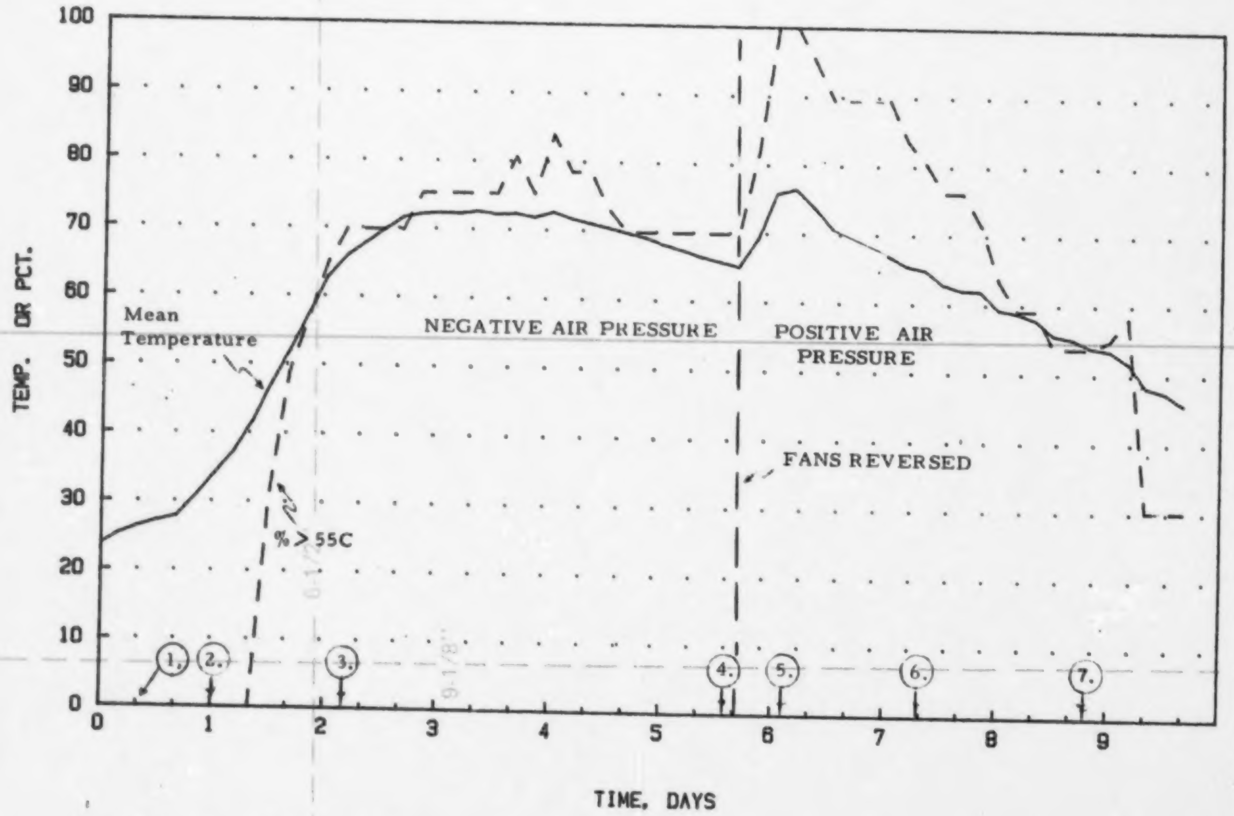


Fig.15 Mean temperature (C) and percent of compost above 55C during Trial VII . Circled numbers indicate times for which temperature distributions were plotted (Figs. 16- 22).

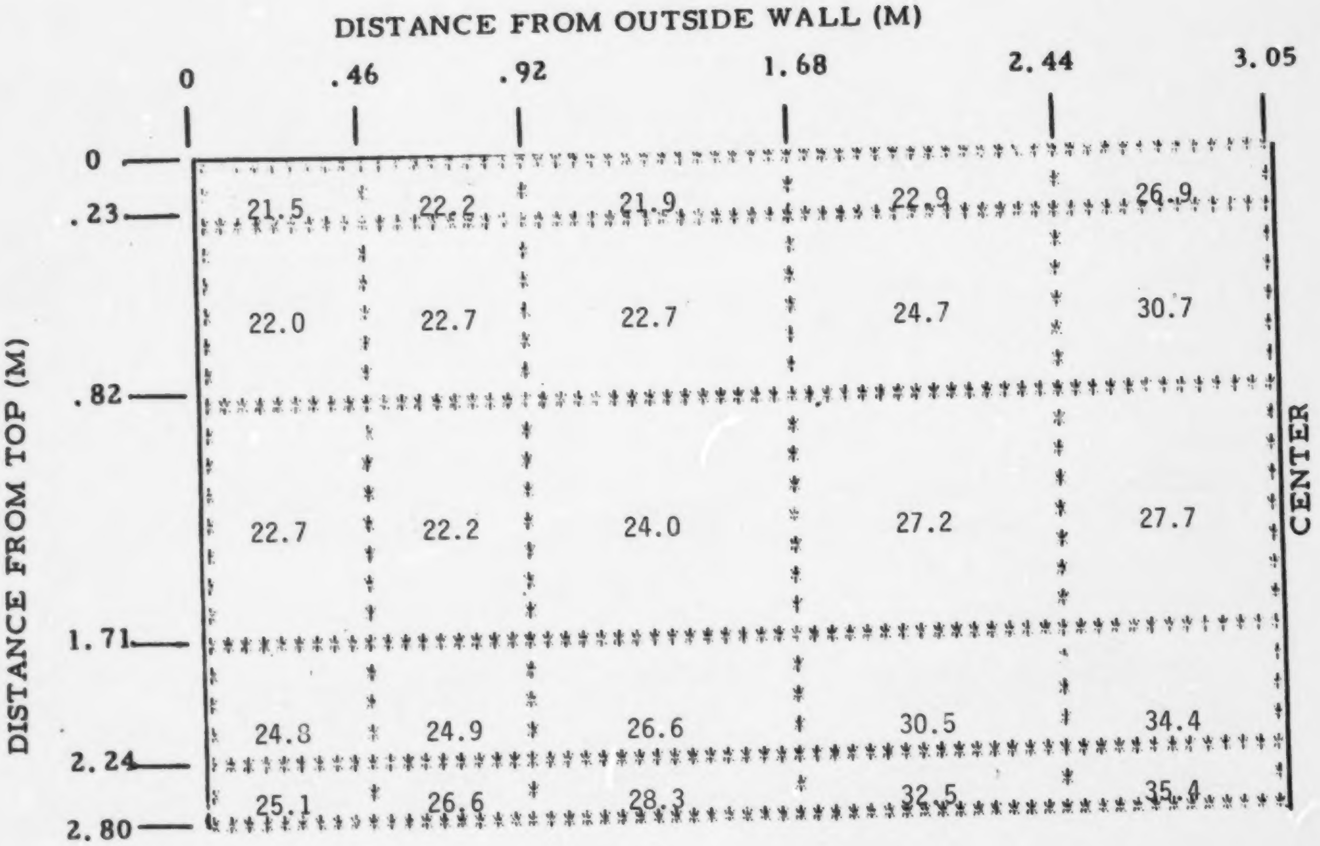
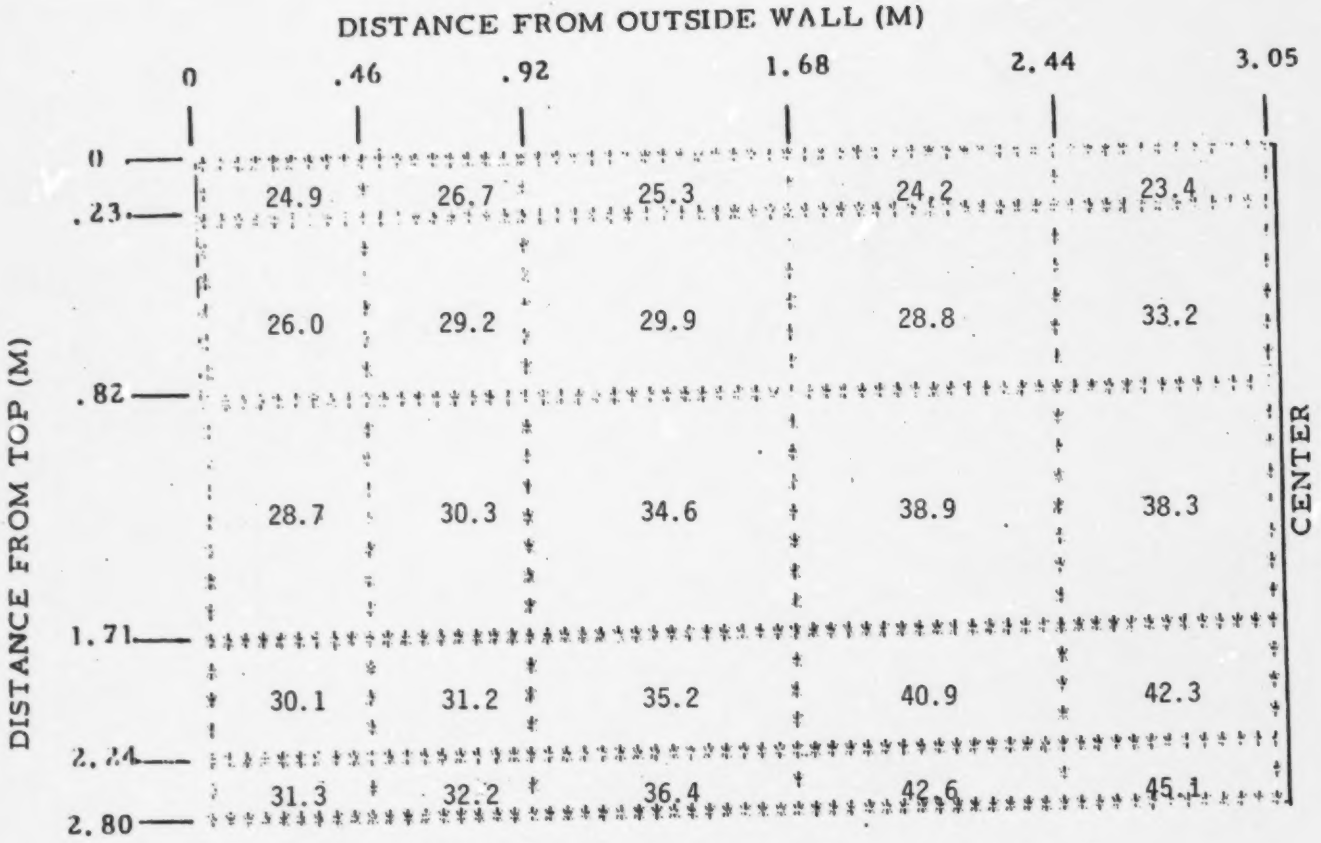
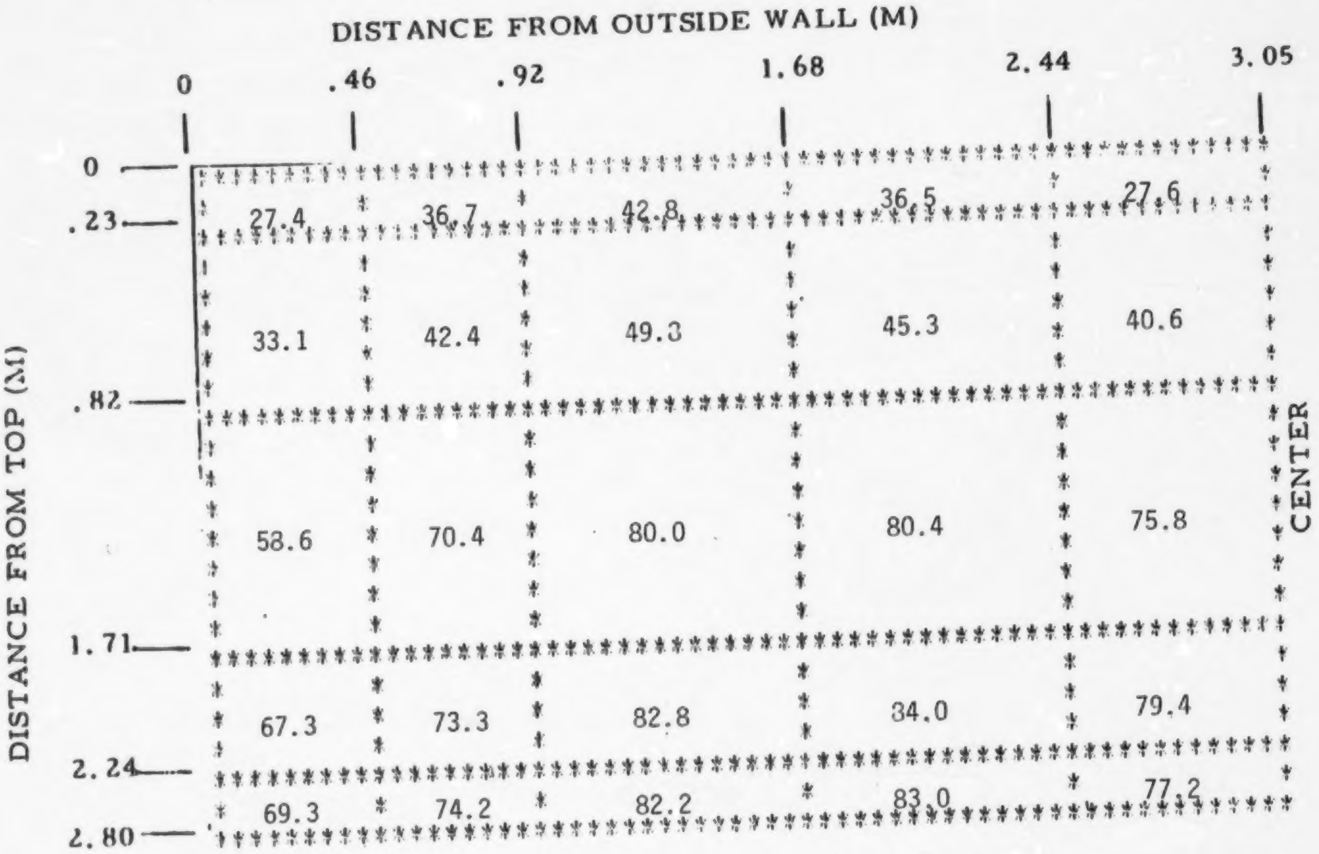


Fig. 16. Temperature distribution at hour 8. Mean Temperature =26. 3 C. Percent of compost above 55 C = 0. 0%.



24.9	26.7	25.3	24.2	23.4
26.0	29.2	29.9	28.8	33.2
28.7	30.3	34.6	38.9	38.3
30.1	31.2	35.2	40.9	42.3
31.3	32.2	36.4	42.6	45.1

Fig. 17. Temperature distribution at hour 24. Mean ttemperature= 33. 9. Percent compost above 55 C = 0. 0%.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DISTANCE FROM TOP (M)
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27.6
33.1
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49.3
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80.4
75.8
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73.3
82.8
34.0
79.4
69.3
74.2
82.2
83.0
77.2

Fig. 18. Temperature distribution at hour 52. Mean temperature = 65.9. Percent of compost above 55 C = 69.8%.

DISTANCE FROM OUTSIDE WALL (M)

DISTANCE FROM TOP (M)	0 – .46	.46 – .92	.92 – 1.68	1.68 – 2.44	2.44 – 3.05 CENTER
0 – .23	52.5	48.7	45.6	41.9	39.6
.23 – .82	53.7	51.1	48.7	46.1	45.5
.82 – 1.71	58.1	64.2	68.2	68.8	68.4
1.71 – 2.24	70.1	73.2	77.9	79.5	78.1
2.24 – 2.80	75.0	77.5	81.4	82.9	81.4

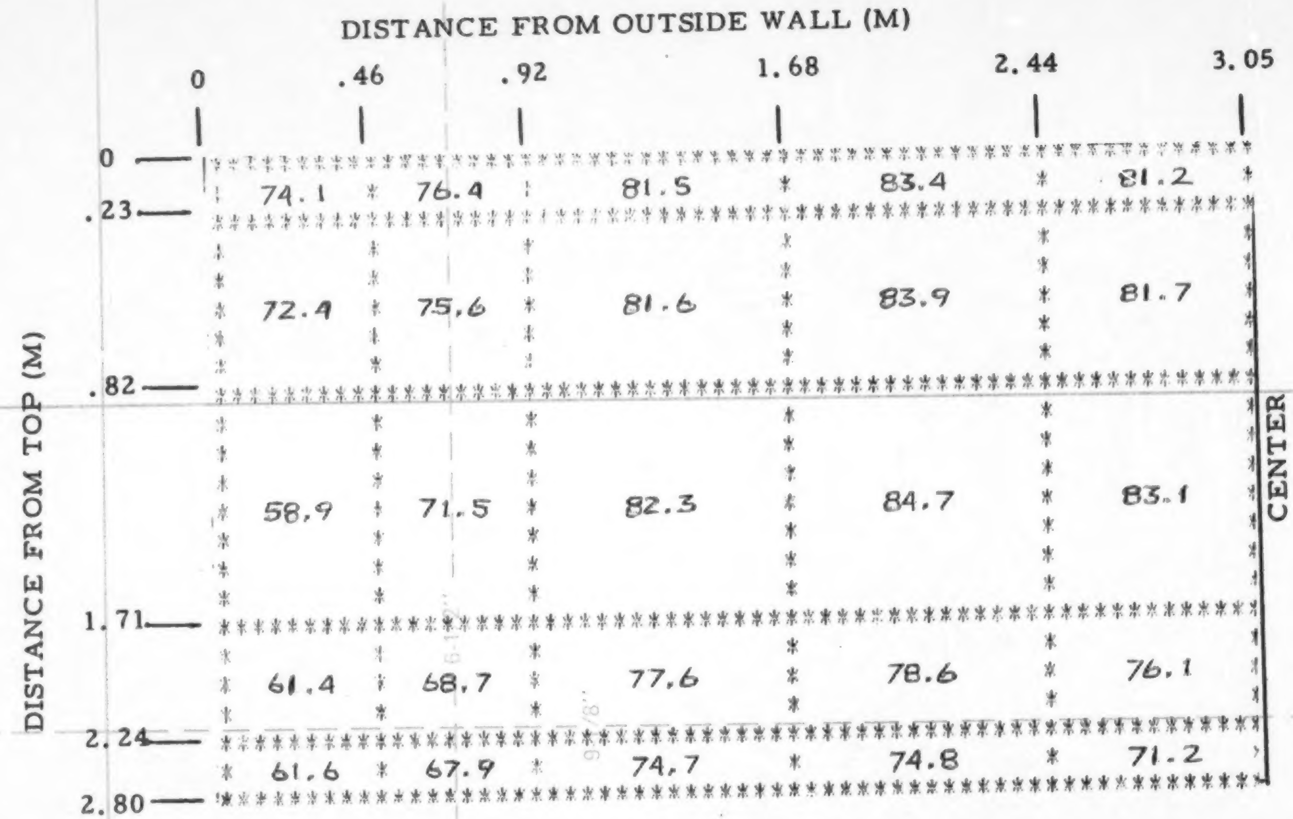
Fig. 19. Temperature distribution at hour 136. Mean temperature = 65 C. Percent of compost above 55C = 69.8 % .

Airflow was reversed on day 5.6. The mean temperature increased sharply and 100% of the compost was >55 C for a brief period (Fig. 20). A steady drop in temperatures occurred thereafter (Figs. 21, 22) and under PPA the highest temperatures once again were near the top of the compost. Thus during this entire reverse airflow procedure 100% of the compost in the reactor had been exposed to 55 C for at least three continuous days. This data shows therefore that the Paygro system can be operated at an efficient temperature for destruction of volatile solids early in the process, followed by a reverse in airflow for pathogen kill purposes.

Although analysis of the fate of fecal pathogens and parasites was not an objective of this research initially, a few standardized tests for survival of coliforms, *Salmonella*, and parasites were performed. The fate of fecal viruses was not examined.

In a preliminary trial during June, 1981, some analyses were performed by J. Robie Vestal, Professor, University of Cincinnati, Cincinnati, OH 45221. Raw municipal sludge was received from the Columbus, Ohio, Southerly Treatment Plant on May 26 and 27, 1981. The reactor feed contained 1×10^9 and 2×10^9 c.f.u. coliforms and *Salmonella*-*Shigella*/g dry wt., respectively. No appreciable numbers of coliforms or *Salmonella* were present in the reactor product after 18 days composting. Details of pathogen assays in this preliminary trial are presented in Appendix IV.

In a second trial in November-December, 1982 (Trial III) analyses were performed by Belmonte Park Laboratories, Div. Elam Testing Co., 1415 Salem Ave., Dayton, OH 45406. Raw primary sludge from the City of Akron was mixed with bulking agents and sampled for pathogens before loading of the reactor. Attempts were made to maintain high temperatures (60C) before the turn in



DISTANCE FROM OUTSIDE WALL (M)
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DISTANCE FROM TOP (M)
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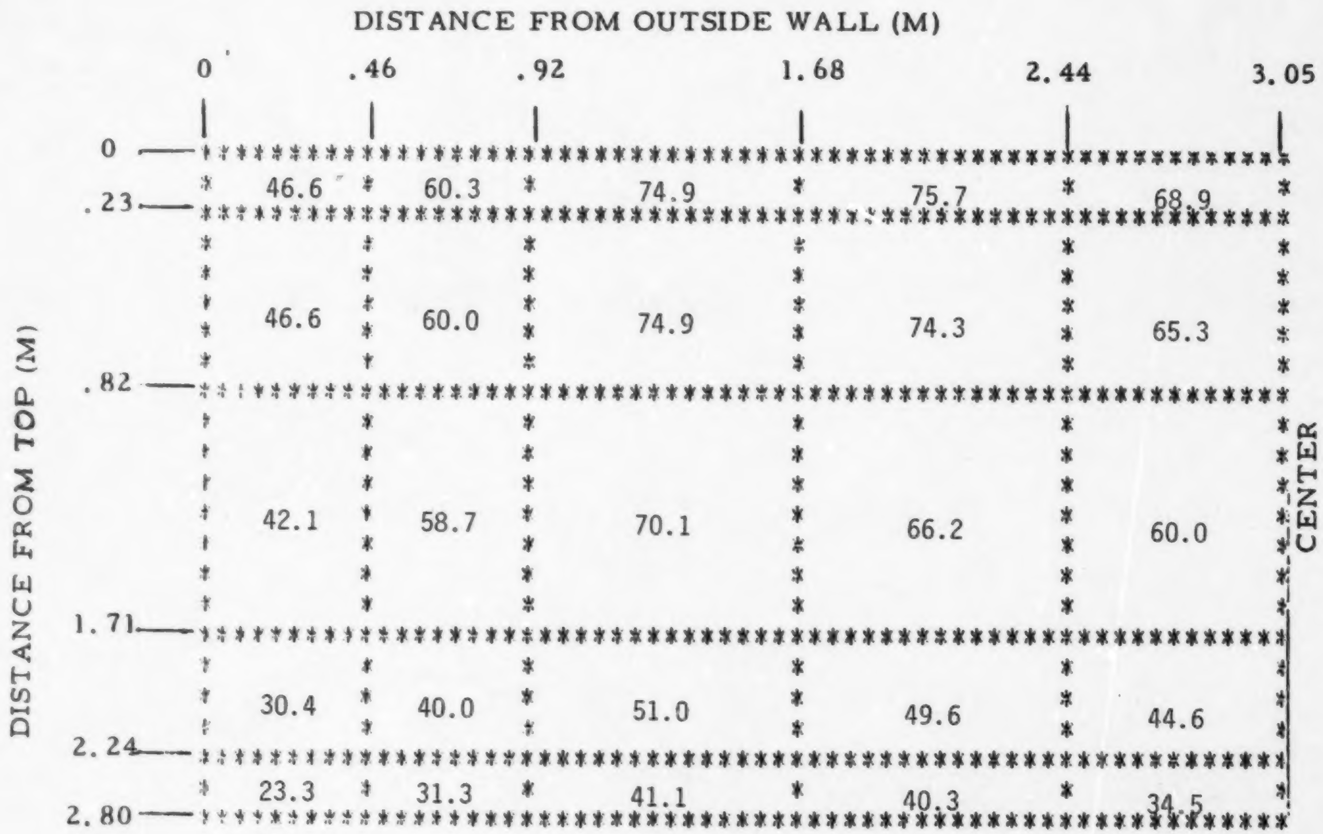
1.71
2.24
2.80
CENTER

	0–.46	.46–.92	.92–1.68	1.68–2.44	2.44–3.05
0–.23	74.1	76.4	81.5	83.4	81.2
.23–.82	72.4	75.6	81.6	83.9	81.7
.82–1.71	58.9	71.5	82.3	84.7	83.1
1.71–2.24	61.4	68.7	77.6	78.6	76.1
2.24–2.80	61.6	67.9	74.7	74.8	71.2

Fig. 20. Temperature distribution at hour 148. Mean temperature = 76.5 C. Percent of compost above 55 C= 100%.

DISTANCE FROM TOP (M)	DISTANCE FROM OUTSIDE WALL (M) 0 – .46	.46 – .92	.92 – 1.68	1.68 – 2.44	2.44 – 3.05 CENTER
0 – .23	55.7	61.8	73.2	78.9	76.7
.23 – .82	55.4	60.7	73.2	78.6	75.6
.82 – 1.71	36.9	57.9	75.1	76.2	71.0
1.71 – 2.24	43.7	55.7	68.3	67.0	61.5
2.24 – 2.80	44.5	54.8	64.4	60.7	52.6

Fig. 21. Temperature distribution at hour 176. Mean temperature = 64.9. Percent of compost above 55 C = 80. 3 %.



46.6	60.3	74.9	75.7	68.9
46.6	60.0	74.9	74.3	65.3
42.1	58.7	70.1	66.2	60.0
30.4	40.0	51.0	49.6	44.6
23.3	31.3	41.1	40.3	34.5

Fig. 22. Temperature distribution at hour 212. Mean temperature = 54.0 C, % volume above 55 C = 53.7

sections 1 and 2 and lower temperatures (45 C) sections 3 and 4. After the turn temperature conditions were reversed with the low temperatures in sections 1 and 2. A materials balance for Trial III is presented in Table 13. Comparison of percent losses in dry solids for all trials (Table 19) shows that trial 3 had the lowest rate of decomposition of all trials even though ambient temperatures were not lowest values for that winter season. Comparison of mean temperature data for trial 3 (Fig. 23) shows that temperatures rose slowly as compared in other trials (e.g. Fig. 9-13). In summary, trial 3 had the worst performance of any trial in this study.

Samples for pathogen testing were processed within 2 hr after they were collected. The most probable number (MPN) of coliforms in the reactor feed ranged from 1.5 to 46.0 x 10^6/gm compost. The M.P.N. for *Salmonella* ranged from 40-230/gm compost. Details of parasites detected and methods used are presented in Appendix Va. After a 15 day compost retention time and one turn, compost was removed from the reactor. The top wet layer in each section (identified as 1-20, 2-19, 3-18 and 4-17 "recycle top" in Appendix Vb) was removed first and sampled. The dryer bottom layer was used as recycle for trial VI and sampled separately (identified as 1-20, etc., "recycle bottom" in Appendix Vb). The M.P.N. for coliforms in the reactor product ranged from 0.9-15 x 10^3/g compost. No *Salmonella* were detected. Some parasites were detected in the reactor product.

The top wet layer was moved into a curing pile out of doors. Temperatures (taken once per week) in the center of the curing pile ranged from 60-70 C during the first three weeks and stabilized at 50-55 C. After 2 months of curing duplicate samples were removed from the center, and from the outer 15 cm layer as well as from two sites 30 cm deep into the pile.

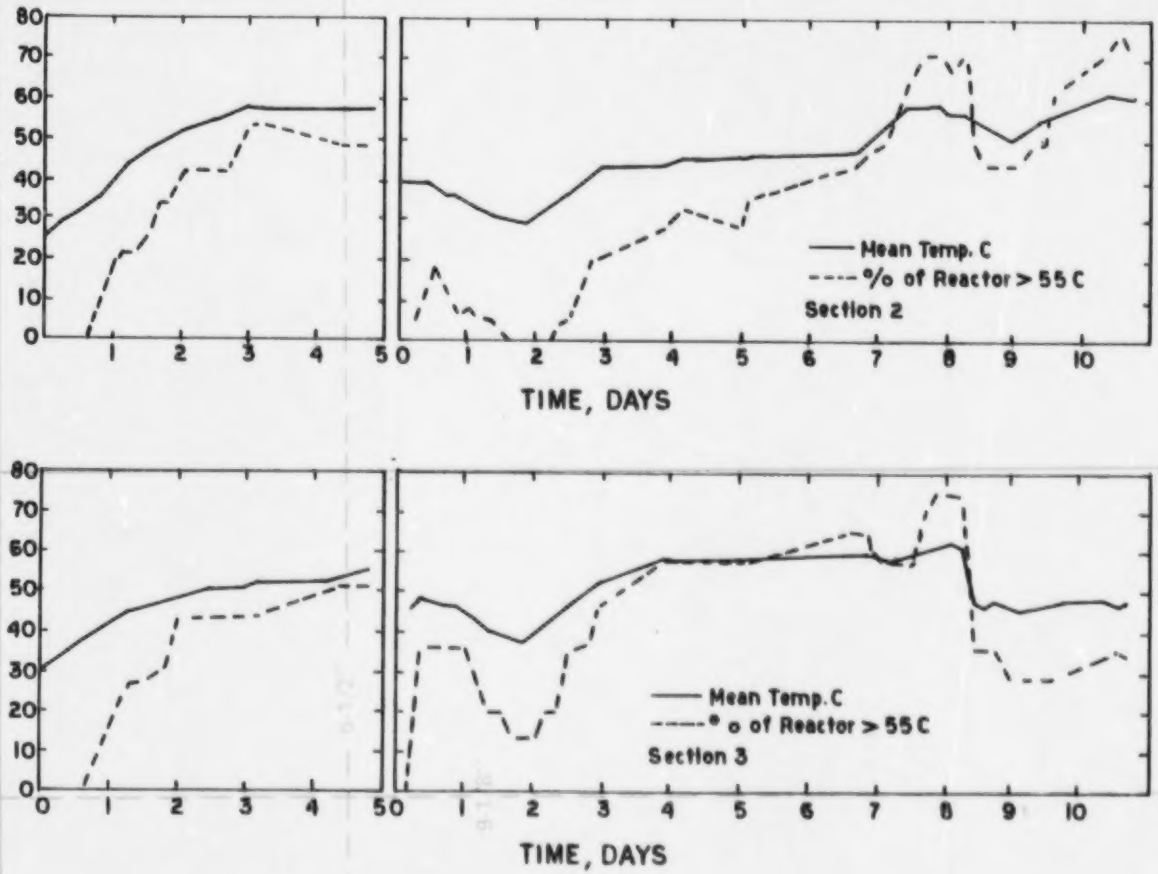


Fig. 23. Mean temperature and % of compost   55 C for two sections (2, 3) of reactor vessel during trial III.

Temperatures in the outer 15 cm layer ranged from 0-30 C whereas those in the 30 cm deep layer ranged from 30-50 C. Coliforms isolated (Appendix Vc) were identified as *E. coli*, *Enterobacter* sp. and *Klebsiella* sp. *Pseudomonas* isolates also were found. Samples from the outer 15 cm layer are identified in Appendix Vc as Storage #1 and #2; those from the 30 cm deep layer as #3 and #4 and those from the center as #5 and #6. The highest coliform counts were detected in the 30 cm deep layer. Counts in the outer layer and center were lowest. No *Salmonella* were detected. Some parasites were found in the outer 30 cm layer. They were dessicated and probably non-viable. No parasite ova were found in samples from the center of the curing pile.

After 4 months of curing additional duplicate samples were removed from the three locations in the curing pile (Appendix Vd). Samples were mixed and divided in half (v/v). One-half (1 liter) of each sample was analyzed by Belmonte Park Laboratories. The other half was analyzed by A. Ottolenghi, Professor, Department of Medical Microbiology, The Ohio State University, Columbus, OH. No potential pathogens were detected in any of the samples (Appendices Vd and e). No evidence for regrowth of *Salmonella* was detected in any of these studies. These results show that pathogens did not survive in those parts of the curing pile where temperatures <55 C occurred over a several week period.

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BULKING AGENTS

In the original proposal considerable emphasis was placed on bulking agent needs for composting of municipal sludge in the Paygro reactor. Much of this work was completed in preliminary trials before complete monitoring equipment was available. A summary of this work is presented here.

Initially coarse bark and fine potting bark were compared as bulking agents. The coarse bark (mostly red oak) was received from sawmills equipped with Hosmer head debarkers. It contained particle sizes ranging from dust to pieces 30 cm long. Potting bark represents the fines screened (rectangular screen, 3/8-3/4 inch opening) out of Hosmer head-debarked bark. During the first preliminary composting trial, in which these bulking agents were compared (January 1981) it was discovered that sludge amended with fine bark did not dry well. In fact the surface layer of compost in the reactor froze, whereas the batch mixed with coarse bark did not freeze. It was decided therefore, to use coarse unprocessed bark as a bulking agent in futher work.

In preliminary trials it was observed that coarse bark mixed with sludges low in dry solids (11-14% DS) did not retain adequate moisture. Therefore, sawdust (mostly from hardwoods) was added to the mixture, which solved this drainage problem. A volumetric ratio of 3 sawdust to 4 bark was eventually chosen as most effective. This mixture was prepared and weighed in advance and added to recycled compost at a mean volumetric ratio of 1 bark-sawdust:4 recycled compost. Sludge was then added to yield a final %

DS of 38-45% in the reactor feed. Since adequate mixing equipment was available for only one trial, the % DS of reactor feed usually ranged from 42-45. This explains the high total bulking agent ratio used in this research as compared in the City of Akron study (Appendix III).

Sawdust added to the compost did not cause nitrogen deficiency on plants produced even in container media amended with 60% composted municipal sludge (CMS). The batch of CMS prepared with bark and sawdust as bulking agents had been cured for only 30 days suggesting that all the sawdust had been decomposed adequately to prevent N deficiency (W. Faber, Department of Horticulture, The Ohio State University, Columbus, OH 43210). This high level of decomposition may also account for the apparent lack of Salmonella regrowth in the compost produced by this system.

Woodchips were used as bulking agents in one trial. The raw sludge-woodchip mixture was prepared at the City of Columbus, OH Southerly Treatment Plant composting facility. The woodchip mixture was loaded into two sections and compared with a bark-sawdust-raw sludge mixture prepared the same day. Severe ammonia losses occurred in the sections of the tank where woodchips were used as bulking agent. This problem did not occur in the bark-sawdust mixture. Probably the total surface area of bulking agent available in the woodchip mixture was inadequate for this highly aerated system. This resulted in carbon deficiency for the microbiota. Therefore deamination occurred and ammonia losses resulted. Woodchips therefore, were not evaluated further as a bulking agent. However a mixture of woodchips, sawdust, ground corn cobs or another finely ground carbon source should be evaluated to verify the possible explanation for the observed phenomenon and to develop other bulking agent combinations for this system.

DISCUSSION

The rate of composting in the Paygro system, even under winter conditions, is very high as compared in other published systems. For example, approximately 30% and 10% of the wet and dry weights, respectively, typically are lost during 42 days of composting (21 days of aeration, 21 days of curing) in the static pile system (13). In the Paygro system in this winter study 25.7 and 9.3% of the wet and dry weights, respectively, were lost but in a mean composting period of only 16.0 days (Table 19). Much higher rates of wet and dry wt losses (40.8 and 15.1% respectively) were found in a 1981 summer trial and in 10 trials performed during 1982 in the Paygro reactor during a City of Akron composting contract (Appendix III).

The metabolism of the microflora in the Paygro reactor seems to be largely aerobic or microaerophilic in nature. Strong odors were not encountered in any of the trials. Although a scentometer was present at the site, it could not be used satisfactorily since minor odors could not be separated from those produced by the feedlot manure system.

The rate of respiration (CO_2 evolution) in the Paygro system was highest over a temperature range of 38-55 C. This specific activity of the compost biota within this temperature range corresponds with that found by J. R. Vestal, University of Cincinnati, for the microflora in this reactor and also with that of continuous composting of mixed refuse in a pilot scale reactor (8, 9, 10).

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In the Paygro system the temperature of the compost is regulated by controlling aeration. Experimental results clearly demonstrated more rapid drying (indicated by change in percent D.S.) and stabilization (change in percent volatile solids) when low temperature (40.95) were maintained with high rates of airflow. In one trial (trial VII) low temperature composting resulted in a 14% loss of the initial weight dry solids in 15 days, whereas high temperature composting produced only a 10% loss. Losses of water and solids given in Table 19 represent averages of a range of composting conditions and are not representative of what could be achieved by temperature control.

Observations made on effects of temperature on rates of composting support those described for various pilot scale systems (8, 9, 10, 15) and the work of MacGregor et al. (11). In the field-scale static pile system of MacGregor et al. (11) airflow was described in terms of "blower demand." This represented the percent of time that blowers (fans) were on. We found trends in "blower demand" and process temperature similar to those published in MacGregor et al. (11) with the highest "demands" at low temperatures. However over the course of a trial, as compost dried and settled marked changes in actual rates of airflow occurred. "Blower demand" therefore does not represent actual quantities of air entering a system. Furthermore, percent CO_2 values in air in a compost pile also do not reflect accurate quantities of CO_2 being exhausted out of a pile. The CO_2 data provided by MacGregor et al. indicate whether the compost microbiota is being supplied with adequate levels of aeration however as MacGregor et al indicated it is not indicative of metabolic activity.

In this study quantitative measurements of airflow were made and thus quantitative measurements on CO_2 evolution were available. In addition the weight of compost in each section was determined during loading at turning and during unloading. In fact measured losses of CO_2 and calculations based on stoichiometric formulae agreed closely (Table 22). Therefore, quantitative comparisons with other published systems indeed are possible.

Haug recently reviewed oxygen consumption rates for various composting mixtures and reaction types as a function of temperature (6). Calculated O_2 consumption values for the Paygro reactor (Table 23) were comparable to rates for bench-scale composters containing a variety of materials (6 mg) (Fig. 14). Rates of CO_2 evolution and of O_2 consumption have not been published for large scale or field-scale composting systems. Many studies on pilot scale systems do not lend themselves to quantitative interpretation since CO_2 balances frequently are not presented. However our data can be compared with data generated for the aerated static pile (7, 14). Their maximum rates (approximately 0.18 mg CO_2/gm VS-hr) are much lower than those in the Paygro system (5.9 mg CO_2/gm VS-hr, Table 23).

A critical aspect of composting is the fate of fecal pathogens. In the aerated static pile an insulating layer is placed over the entire pile so that all parts of the compost are exposed to temperatures >55 C for three continuous days (12). Rates of aeration in that systems are low, resulting in low rates of composting. On the other hand in the Paygro system high rates of decomposition and negligible odor problems are obtained by the high aeration rates. Therefore, under these conditions significant volumes of compost at any one time do not meet the criteria for "further reduction of pathogens." Compost in the Paygro System however, can be turned, so that all compost eventually meets the criteria. Furthermore data presented in this work clearly show that reversing the direction of airflow effectively exposes all compost in the reactor to the >55 C conditions. Thus high temperature was applied successfully after low temperature treatment showing that maximum rates of stabilization indeed could be paired with adequate levels of pathogen destruction and yet maintain aerobic conditions to avoid odors.

All of the reactor feed used in this study was mixed by FEL, with the exception of parts of trial V. High rates of drying were observed during mid-winter (January) in the pugmill-mixed compost. The importance of preparing a "homogeneous mix has been stressed in the literature (7, 17). In all except this trial compost was not mixed adequately until after the first turn, when the extractoveyor removed the compost from the reactors. Estimates on drying obtained in this study (Table 19) therefore are conservative as compared with results which could be obtained in a Paygro system specifically designed for sludge. In the manure system at Paygro, excrement is mixed with bedding by the "walking" of the cattle on the mixture in the pens. A specific mixing system other than FEL therefore is not necessary at the facility where this research was performed.

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Appendix I. Calculations for the determination of airflow, mass (Kg) of dry air entering the reactor and mass (Kg) of carbon dioxide produced during each four hour interval.

The airflow through the ducts is a function of the size of the opening of the duct and air velocity and can be determined by the formula:

(1) $$Q \text{ (cubic ft./min.=FCM)} = V*A$$

where V=air velocity
A=cross sectional area of duct

The velocity of the air was determined from the differential pressure measured by the averaging pitot tubes inserted in each fan duct using the formula:

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(2) $$V \text{ (feet/sec)} = \sqrt{\frac{225.43 * h * T}{P}}$$

where h=differential pressure, inches of water
T=air temperature, K(=273.16 + C)
P=atmospheric air pressure, 30 inches Hg

Combining equations 1 and 2 and knowing the diameter of the duct (16"), Q in cubic feet/min was determined from the formula:

(3) $$Q = 83.7 \left(\frac{225.43\ T}{P} \right)$$

Since airflow is a function of atmospheric conditions, Q at standard temperature and pressure conditions was determined using the following relationship:

(4) $$Q \text{ (std)} = Q \left(\frac{P}{-29.92} \right) \times \left(\frac{294.27}{T} \right)$$

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Equations 3 and 4 were combined to yield the following formula for determination of the airflow:

(5) $$Q\ (std) = 12,359.3 \sqrt{\frac{P*h}{T}}$$

Conversion to metric units (cubic meters/min) was achieved by multiplying by the constant .0283.

Using the Q(std) it was then possible to determine the mass of air (Kg) that passed through the reactor. The Kg of dry air was determined using relationships for ideal gases. The derivation of the following formula is given by T. Haug on pp. 385-388 in Compost Engineering, Ann Arbor Science, Inc., Ann Arbor, MI.

(6) $$\text{Dry Air (Kg/min)} = \frac{1.0 \text{X}10^5 \left(\frac{760-PV}{760}\right) Q}{287.0\ *T}$$

where Q=cubic meters/min
T=air temperature in degrees K
PV=actual water vapor pressure (calculated using relative humidity and temperature readings)

The amount of time that the fans were on during each 4 hr interval was recorded (FON) and was used in the following formula to determine the Kg of dry air that entered the reactor during a 4 hr time period:

(7) $$\text{Dry Air (Kg/4 hr)} = \text{Dry Air (Kg/min)} \left(\frac{T*\ FON*\ .06}{287}\right)$$

Given that the air leaving the reactor was equal to that entering the reactor, the mass of carbon dioxide produced during each 4 hr interval was determined using the relationship:

(8) $$CO_2\ \text{(Kg/4 hr)} = (\%\ CO_2 - .05)\ \text{(Kg dry air/4 hr)/100}$$

Appendix II. Interpolation of temperature data

The following problem is the subject of this memo. Temperature readings are available at N locations over a rectangular area. The i-th location has coordinates (x_i , y_i) and its temperature is T_i . We wish to assign a temperature value to any arbitrary point (x^*,y^*) in the plane. This will allow one to compute such items as (a) spatially averaged temperature, (b) isotherm contours, or (c) percent of the area within a given temperature range.

Problems of this type are similar to those of mapping areal rainfall in hydrology. Reviews of techniques applicable to these problems have been written by Hall and Barclay (1975) and Creutin and Obled (1982). The simplest class of techniques to use is known as surface fitting. It assumes that temperature can be expressed as some known function of x and y,

$$T = f(x,y)$$

The function f will contain certain parameters or coefficients whose values are derived from the known measurements according to a particular least-squares fitting or interpolating criterion. Two such techniques, each with different surface functions and parameter estimation criteria, will now be discussed.

Quadratic Interpolation (Chidley and Keys, 1970)

Let T be described by the following function

$$T = a_1x + a_2x^2 + a_3xy + a_4y^2 + a_5y + a_6$$

where a_1 to a_6 are coefficients. Their values are determined as follows.

From the N observed values of T we have the following set of equations

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$$\begin{bmatrix} x_1 & x_1^2 & x_1y_1 & y_1^2 & y_1 & 1 \\ x_2 & x_2^2 & x_2y_2 & y_2^2 & y_2 & 1 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_N & x_N^2 & x_Ny_N & y_N^2 & y_N & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ . \\ . \\ a_6 \end{bmatrix} = \begin{bmatrix} T_1 \\ T_2 \\ . \\ . \\ T_N \end{bmatrix}$$

or in compact form

$$\underline{F}\,\underline{A} = \underline{T}$$

Since N will usually be greater than 6 this system of equations is overdetermined. $\underline{A}$ can be estimated by a least squares criterion, i.e., by minimizing the quantity $(\underline{F}\,\underline{A} - \underline{T})^2$. This leads to the solution

$$\underline{A} = (\underline{F}^t\,\underline{F})^{-1}\,\underline{F}^t\,\underline{T}$$

where $\underline{F}^t$ denotes $\underline{F}$ transpose. The spatially averaged temperature, T_{avg}, can be easily computed as

$$T_{avg} = a_1W^2H/2 + a_2W^3H/3 + a_3W^2H/4 + a_4WH^3/3 + a_5WH^2/2 + a_6WH$$

where W = width of area in the x direction and H = height of the area in the y direction.

Spline Interpolation (Creutin and Obled, 1982)

One problem associated with quadratic interpolation is the tendency for the temperature function to oscillate wildly between the measurement points. To overcome this problem it has been suggested that a spline function be used as an interpolant, subject to certain smoothness criteria. One such criterion is to minimize the follwoing functional

$$\int_R \{\nabla f(x,y)\}^2\,dR$$

where $\nabla f(x,y) = \partial^2T(x,y)/\partial x^2 + 2$[illegible] $+ \partial^2T(x,y)/\partial y^2$.
This is a first approximation of [illegible]ge curvature or bending energy of

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a thin elastic sheet spread over the x-y region R with height T_i at the points (x_i, y_i).

The unique function that satisfies such a criterion is given by

$$f(x,y) = a_0 + a_1 x + a_2 y + \sum_{i=1}^{N} c_i K(x_i, x, y_i, y)$$

where $K(x_i,x,y_i,y) = \{(x_i-x)^2 + (y_i-y)^2\}\log\{(x_i-x)^2 + (y_i-y)^2\}$.
The coefficients a_0, a_1, a_2, c_i, i= 1 to N, are determined by solving the following set of N+3 equations:

$$a_0 + a_1 x_i + a_2 y_i + \sum_{j=1}^{N} c_j K(x_i, x_j, y_i, y_j) = T_i \quad i = 1, \ldots, N$$

$$\sum_{j=1}^{N} c_j = 0$$

$$\sum_{j=1}^{N} c_j x_j = 0$$

$$\sum_{j=1}^{N} c_j y_j = 0$$

This method gives most satisfactory results when the statistical errors in the observed T values are small. An extension of the method that includes a smoothing criterion seeks to minimize

$$\int_R \{\nabla f(x,y)\}^2 \, dR + \rho \sum_{i=1}^{N} \{ T_i - f(x_i,y_i) \}^2$$

where ρ is an appropriately chosen weighting parameter.

The computational effort in using the spline technique is greater than for quadratic interpolation. This also applies to the effort required to evaluate the temperature function f(x,y). This makes additional computations, such as finding spatial averages or contour plotting, more difficult.

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Chidley and Keys, "A rapid method of computing area rainfall", *J. Hydrol.*, 12:15 (1970).

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Creutin, J.D. and Obled, C., "Objective analysis and mapping techniques for rainfall fields: An objective comparison", *Water Resources Research,* 18:413, (1982).

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Appendix III

Paygro System
Process Performance Summary

Summarized from Akron Composting Demonstration Project, City of Akron, March, 1983. Burgess and Niple, Limited, 46 South Summit Street, Akron, OH

Shown in Table 1 are the average characteristics of the components used during the composting trials along with the volumetric mix ratios utilized. Also shown are the dry solids, volatile solids and bulk weights of the average reactor feed and reactor product during the evaluation.

Trials 1 thru 3 were designated as a "start-up" phase since a high ratio of bark and sawdust was required to produce sufficient recycle for subsequent trials. During this start-up phase the volumetric mix ratios averaged 1.0 sludge to 1.06 bark and sawdust to 1.46 recycled compost.

Steady state conditions were achieved during Trials 4 thru 8. At steady state the volumetric mix ratios averaged 1.0 sludge to 0.39 bark and sawdust to 1.21 recycle.

Trials 9 and 10 were designated "re-start" because a large amount of finished product was shipped following Trial 8 to meet the requirements of a marketing evaluation. This shipment of finished product left insufficient compost available for use as a bulking agent during Trial 9. Compost generated during Trials 9 and 10 was utilized as the recycle component for subsequent studies conducted by OARDC. The volumetric mix ratios for the re-start phase averaged 1.0 sludge to 0.82 bark and sawdust to 1.07 recycle.

Detailed materials balances for two representative trials are presented in Tables 2 and 3. Trial 4 represents cold weather operation at an average ambient temperature of approximately 5°C while Trial 7 was conducted at warmer temperatures averaging about 20°C.

Table 4 summarized Paygro System performance for all 10 trials. For steady state conditions, represented by Trials 4 thru 8, the reactor feed averaged 41.9% DS and the system yielded a reactor product which averaged 61.4% DS. At a mean retention time of 16.7 days the Paygro System resulted in a total weight loss of 47.2%, a dry solids weight loss of 22.8%, a volatile solids weight loss of 28.1% and a moisture reduction of 64.8% (excluding water generated through biological activity).

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TABLE 1

COMPONENT CHARACTERISTICS AND MIX RATIOS

				VOLUMETRIC MIX RATIOS		
				TRIALS		
COMPONENT	% DS	% VS	LBS/CU.FT.	1 - 3 START-UP	4 - 8 STEADY STATE	9 - 10 RESTART
Sludge	26.7	64.7	56.7	1.0	1.0	1.0
Bark & Sawdust	66.2	90.0	21.7	1.06	0.39	0.82
Recycle	60.2	63.9	33.6	1.46	1.21	1.07
Reactor Feed	41.9	68.4	40.8			
Reactor Product	61.4	63.6	33.6			

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TABLE 2

TRIAL #4 MATERIALS BALANCE, AKRON, OHIO SLUDGE AT 22% DS
COMPOST RETENTION TIME 15.25 DAYS, APRIL 1982

	WEIGHT (TONS)	VOLUME (CU.FT.)	BULK WEIGHT (LB/CU.FT.)	% DRY SOLIDS	% VOLATILE SOLIDS	WEIGHT DS (TONS)	WEIGHT VS (TONS)	WEIGHT WATER (TONS)
FEED COMPONENT								
SLUDGE	169.6	5,653	60.0	22.0	70.0	39.0	27.3	130.6
RECYCLE	169.6	9,975	34.0	53.4	69.8	90.6	63.2	79.0
BARK	37.0	3,365	22.0	62.0	90.0	23.0	20.7	14.0
FEED MIXTURE	376.2	18,993	39.6	40.5	72.9	152.6	111.2	223.6
FINISHED COMPOST	207.4	12,200	34.0	56.7	66.3	117.7	78.0	89.7
LOSS DURING TRIAL	168.8	6,793				34.9	33.2	133.9
% LOSS	44.9	35.8				22.8	29.8	59.9

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TABLE 3

TRIAL #7 MATERIALS BALANCE, AKRON, OHIO SLUDGE AT 31.9% DS
COMPOST RETENTION TIME 17 DAYS, JUNE 1982

	WEIGHT (TONS)	VOLUME (CU.FT.)	BULK WEIGHT (LB/CU.FT.)	% DRY SOLIDS	% VOLATILE SOLIDS	WEIGHT DS (TONS)	WEIGHT VS (TONS)	WEIGHT WATER (TONS)
FEED COMPONENT								
SLUDGE	220.2	8,007	55.0	31.9	62.4	70.2	43.8	150.0
RECYCLE	73.4	4,590	32.0	67.7	66.1	49.7	32.9	23.7
BARK	23.7	2,155	22.0	64.0	90.0	15.2	13.6	8.5
FEED MIXTURE	317.3	14,752	43.0	42.6	66.8	135.1	90.3	182.2
FINISHED COMPOST	170.1	9,720	35.0	56.6	62.0	96.3	59.7	73.8
LOSS DURING TRIAL	147.2	5,032				38.8	30.6	108.4
% LOSS	46.4	34.1				28.7	33.9	59.5

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TABLE 4

PAYGRO SYSTEM PERFORMANCE SUMMARY, 10 TRIALS
AKRON, OHIO RAW PRIMARY SLUDGE

	TRIAL							MEAN
	1-3	4	5	6	7	8	9-10	4-8
DRY SOLIDS (%) OF:								
REACTOR FEED	36.8	40.5	42.2	42.0	42.6	42.3	45.0	41.9
REACTOR PRODUCT	48.1	56.7	58.8	67.7	56.6	66.6	67.2	61.4
% LOSS IN:								
WET WEIGHT	34.9	44.9	49.8	48.1	46.4	46.7	40.8	47.2
WEIGHT DS	15.0	22.8	30.0	16.3	28.7	16.0	11.5	22.8
WEIGHT VS	22.2	29.8	35.1	22.3	33.9	19.3	17.6	28.1
WEIGHT H_2O	46.6	59.9	64.3	71.0	59.5	69.1	64.7	64.8
DAYS RETENTION	32.8	15.3	17.5	21.8	17.0	11.8	19.8	16.7
MEAN TEMPERATURE OF AMBIENT AIR (°C)								
HIGH	1.1	9.7	20.4	23.3	23.9	28.5	25.9	21.2
LOW	-4.4	2.5	10.2	16.3	15.6	20.1	17.1	12.9

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The results of the ten Akron sludge trials, from a process design standpoint, indicated that:

1. A 14 day retention period is sufficient except during severely cold weather.
2. Volumetric mix ratios of fresh bulking agent, i.e. bark and sawdust, of as low as 0.26 are adequate as long as sufficient recycled compost is utilized to produce a reactor feed solids concentration of 40%.
3. Moisture reductions of 60 to 70% (excluding water generated by biological activity) can be expected for steady state operating conditions.
4. The Paygro System can generate a product with dry solids concentration in excess of 62% in a 14 day retention period.

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Appendix IV.

University of Cincinnati

College of Arts and Sciences
Department of Biological Sciences
Cincinnati, Ohio 45221

September 22, 1981

Dr. Harry Hoitink
Department of Plant Pathology
OARDC
Wooster, Ohio 44691

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Dear Harry:

We checked the "cured" compost from the last run of Columbus sludge for coliforms and Salmonella-Shigella. The procedine and results are as follows:

> 5g wet weight = (3.55g dry wt.) into 100ml of sterile buffer, blended for 30 sec, allowed to settle for 10 min, plated 0.5 and 0.1ml onto EMB and SS agar in triplicate.

While there were a lot of bacteria, there were no pathogens detected. If there were appreciable numbers of pathogens, I am sure they would have been detected. This means that there were less than 281 pathogens per gram dry weight of compost.

I hope that these data will be useful to you.

See you soon.

Sincerely,

J. Robie Vestal, Ph.D.
Associate Professor of
Biological Sciences

JRV:mk

cc: Dr. Atal Eralp

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Appendix Va

Belmonte Park Laboratories

DIVISION OF ELAM TESTING COMPANY

MEDICAL DIVISION, Phone 513-278-4181
Upper Level, Elam Science Bldg.

INDUSTRIAL DIVISION
Lower Level, Elam Science Bldg.

1416 SALEM AVE.
DAYTON, OHIO 45406

Dr. Harry Hoitink, Ph. D.
Professor of Plant Pathologeforms
O.A.R.D.C.
Wooster, Ohio 44641

REPORT TO: Dr. Harry Hoitink, Ph. D.

REPORT ON: Sludge analysis collected at the Paygro Plant, South Charleston, Ohio.

PROJECT NO: HH82001

Date received: 11-12-82

Date reported: 11-24-82

RESULTS:

	SAMPLE I.D.	COLIFORM	SALMONELLA	ASCARIS
1.	# 1	MPN: 9,300,000/ gm	MPN: 40/ gm	No ova found
2.	# 2	MPN: 1,500,000/ gm	MPN: 230/ gm	No ova found
3.	# 3	MPN: 46,000,000/ gm	MPN: 90/ gm	No Ascaris ova found. Taenia species Diphyllobothrium s
4.	# 4	MPN: 4,300,000/ gm	MPN: 150/ gm	No ova found

On sample # 3: 1 Taenia species, Diphyllobothrium species

The results for Salmonella and coliform are reported in terms of "Most probable number" (MPN) and result from multiple-portion decimal dilutions of the sludge samples. Positive results are confirmed by further testing and the numbers of positives at different decimal dilutions lead to the production of the MPN result by statistical methods.

REFERENCE: "STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 15th. edition".

Respectfully submitted,

J. A. Elam
J. A. Elam, B.L.D.
President & Director

R. Daneman
Chief Microbiologist

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MEDICARE CERT. NO. 36-8026 U.S. ATOMIC ENERGY COMMISSION REGISTRATION NO. 1880 OHIO CERT. NO. 78
OHIO ENVIRONMENTAL PROTECTION AGENCY APPROVAL NO. 857 FOOD AND DRUG ADMINISTRATION REGISTRATION NO. 15823774

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Appendix Vb

Belmonte Park Laboratories

DIVISION OF ELAM TESTING COMPANY

MEDICAL DIVISION, Phone 513-279-4181
Upper Level, Elam Science Bldg.

INDUSTRIAL DIVISION
Lower Level, Elam Science Bldg.

1416 SALEM AVE.
DAYTON, OHIO 45406

Dr. Harry Hoitink,
Professor of Plant Pathologeforms
O.A.R.D.C.
Wooster, Ohio 44641

PAGE 1 of 2 PAGES

REPORT TO: Dr. Harry Hoitink, Ph. D.

REPORT ON: Sludge analysis collected at the Paygro Plant, South Charleston, Ohio

PROJECT NO: HH82002

Date received: 12-6-82
Date reported: 12-15-82

RESULTS:

SAMPLE I.D.	COLIFORM	SALMONELLA	ASCARIS
1. Section #1-20 recycle top	MPN: 4,300/ gm	Negative	No ova found
2. Section #1-20 recycle bottom	MPN: 900/ gm	Negative	No ova found
3. Section # 2-19 recycle top	MPN: 1,500/ gm	Negative	One ovum of: Taenia species
4. Section # 2-19 recycle bottom	MPN: 15,000/ gm	Negative	Two (2) rhabditiform larv Strongyloides stercoralis One (1) cyst Entamoeba co
5. Section # 3-18 recycle top	MPN: 9,300/ gm	Negative	One (1) ovum Ascaris lumbricoides One (1) ovum Taenia specie Three (3) rhabditiform larv Strongyloides stercoralis

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OHIO ENVIRONMENTAL PROTECTION AGENCY APPROVAL NO. 867 FOOD AND DRUG ADMINISTRATION REGISTRATION NO. 10883776

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Appendix Vb cont.

Belmonte Park Laboratories   DIVISION OF ELAM TESTING COMPANY

PAGE 2
Dr. Harry Hoitink,
12-15-82

6. Section # 3-18 recycle bottom	MPN:	11,000/ gm	Negative	No ova found
7. Section # 4-17 recycle top	MPN:	11,000/ gm	Negative	No ova found
8. Section # 4-17 recycle bottom	MPN:	2,400/ gm	Negative	No ova found

The results for Salmonella and coliform are reported in terms of "Most probable number" (MPN) and result from multiple-portion decimal dilutions of the sludge samples. Positive results are confirmed by further testing and the numbers of positives at different decimal dilutions lead to the production of the MPN result by statistical methods.

REFERENCE: "STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 15th. edition".

Respectfully submitted,

J. A. Elam, B.L.D.
President & Director

R Daneman
R. Daneman
Chief Microbiologist

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

Appendix Vc

Belmonte Park Laboratories DIVISION OF ELAM TESTING COMPANY

Dr. Harry Hoitink
Professor of Plant Pathologeforms
O.A.R.D.C.
Wooster, OH 44641

Page 1 of 2 pages

REPORT TO: Dr. Harry Hoitink

REPORT ON: Sludge analysis collected at the Paygro Plant, S. Charleston,

PROJECT NO: HH83001 Date Received: 2-22-83 Date Reported: 3-1-8

RESULTS

SAMPLE I.D.	DEPTH IN PILE (CM)	COLIFORM	SALMONELLA	ASCARIS
1. Trial III, Storage #1	15	MPN: 460/ gm	Negative	No ova seen
2. Trial III, Storage #2	15	MPN: 240/ gm	Negative	Two (2) ova Enterobius vermicularis
3. Trial III, Storage #3	30	MPN: 1,100/ gm	Negative	Four (4) ova Ascaris lumbricoid One (1) Enterobius vermicularis
4. Trial III, Storage #4	30	MPN: 1,100/ gm	Negative	No ova seen
5. Trial III, Storage #5	Center	MPN: 23/ gm	Negative	No ova seen
6. Trial III, Storage #6	Center	MPN: 93/ gm	Negative	No ova seen

The results for coliform are reported in terms of "Most probable number" (MPN) and result from multiple-portion decimal dilutions of the sludge samples. Positive results are confirmed by further testing and the number of positives at different decimal dilutions lead to the production of the MPN result by statistical methods. On re-isolation, coliforms were found to include E. Coli, Enterobacter species, and Klebsiella species. Pseudomonas were also found.

Parasite ova seen were in dessicated form and probably non-viable.

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Appendix Vc cont.

Belmonte Park Laboratories DIVISION OF ELAM TESTING COMPANY

Page 2
Dr. Harry Hoitink
3-1-83

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REFERENCE: "STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 15th edition".

9-1/8''

Respectfully submitted,

J. A. Elam

J. A. Elam, B.L.D.
President & Director

R Daneman

R. Daneman
Chief Microbiologist

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TYPING GUIDE SHEET

Appendix Vd

Belmonte Park Laboratories DIVISION OF ELAM TESTING COMPANY

Dr. Harry Hoitink
Professor of Plant Pathologeforms
O.A.R.D.C.
Wooster Ohio 44641

REPORT TO: Dr. Harry Hoitink

REPORT ON: Compost samples for pathogens

PROJECT NO: HH 83002 Date Received: 4-13-83 Date Reported: 4-21-83

RESULTS

SAMPLE I.D.	COLIFORM	SALMONELLA	ASCARIS
1. Trial III #1	MPN: 460 / gm	Negative	No ova seen
2. Trial III #2	MPN: 43 / gm	Negative	No ova seen
3. Trial III #3	MPN: 1,100/ gm	Negative	No ova seen
4. Trial III #4	MPN:>2,400/ gm	Negative	No ova seen
5. Trial III #5	MPN >2,400/ gm	Negative	No ova seen
6. Trial III #6	MPN:>2,400/ gm	Negative	No ova seen

The results for Salmonella and coliform are reported in terms of "Most probable number" (MPN) and results from multiple-portion decimal dilution of the compost samples. Positive results are confirmed by further testing and the numbers of positives at different decimal dilutions lead to the production of the MPN result by statistical methods.

REFERENCE: "STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER,15th.edition"

Respectfully submitted,

James A. Elam
James A. Elam, B.L.D.
President & Director

R Daneman
R. Daneman
Chief Microbiologist

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Appendix Ve

OSU

The Ohio State University

Department of
Medical Microbiology
and Immunology
333 West 10th Avenue
Columbus, Ohio 43210
Phone 614 422-5525

RESULTS OF THE EXAMINATION OF SLUDGE COMPOST FROM TRIAL III

Samples numbered 1-6
Received 4/13/83
Examination started 4/14/83

MOISTURE CONTENTS

Sample #	1	2	3	4	5	6
% moisture	40%	40%	60%	64%	64%	54%

EXAMINATION FOR SALMONELLA

No Salmonellae found in any specimen. 8 gms. wet weight of each sample was suspended in 32 ml of sterile water. Final concentration 20%.

Method sensitivity: (Recovery of seeded Salmonellae) ca. 35 CFU/ml of suspension.

EXAMINATION FOR PARASITES.

A sample of approximately 20 grams (dry weight equivalent) of the compost was examined. Following treatment with hypochlotite, detergent and washing the eggs were floated on zinc sulfate (sp. g-1.2).

No Ascaris nor other human parasits eggs were seen. Great numbers of mite eggs were recovered.

EXAMINATION FOR COLIFORMS.

An attempt was made to count coliform by the filter membrane method (Standard Methods (14th Ed.)). Because of the relative high number of non-coliform present the results are not considered to be reliable. No coliforms were seen at a dilution of 4×10^{-6} in samples 3 and 4, the first dilution giving a readable membrane. No coliforms were seen in samples 1,2,5 and 6 at a dilution of 4×10^{-5}.